Project Briefs for

SHRP 2 Renewal Research

Bridges

Nondestructive Testing

Pavements

Project Delivery

Utilities and Railroads

March 2014

Tomorrow's Bridges

A Renewal Project Brief Summarizing Bridge Research in SHRP2

APRIL 2011

Durability is a problem for today's bridges. Bridge components break down. Soils become unstable. Bridge decks deteriorate, often unnoticed. Replacing bridges can be costly, time-consuming, and disruptive to traffic. And the cycle repeats as bridges age. Innovative methods have been developed for designing and constructing new bridges, repairing existing bridges, stabilizing bridge foundations, and nondestructively testing bridges; but they are not routinely used. Today's innovations, however, can become tomorrow's standards.

The second Strategic Highway Research Program (SHRP 2) is working closely with the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) to make today's innovations more commonplace. Resolving obstacles to implementing innovation will mean that bridges can be created and replaced faster and be much more durable. Tomorrow, it will be standard for a bridge to have a service life of more than 100 years.

Bridge Foundations

The long-term performance of bridges is directly related to the stability of the subsurface. Traditional approaches for dealing with deformation and stability are too time-consuming for rapid renewal projects. In 1996, FHWA's geotechnical group of the bridge division enhanced the transportation community's acceptance and implementation of ground improvement methods in Demonstration Project 116, "Ground Improvement Methods." However, nongeotechnical constraints—such as the proximity of utilities, project geometry, and traffic—can limit the application of potential geotechnical solutions. Many innovations have been created since the 1990s, but they are rarely used because both technical and nontechnical obstacles prevent their broad application. The obstacles include lack of simple, comprehensive, reliable, and nonproprietary analysis and design procedures; costs for design, construction, quality control/quality assurance, and maintenance; performance uncertainty; and lack of suitable model specifications.

As these obstacles are overcome, today's innovations become tomorrow's standard practice. Column-supported embankments, reinforced soil slopes and platforms, and lightweight fills will be standard methods for creating and widening bridges over unstable soils. Intelligent compaction, geosynthetic reinforced platforms, high-energy compact rollers, and chemical and mechanical subgrade stabilization will be standard tools for stabilizing bridge working platforms. These standards

will be used in rapid renewal projects that cause minimum disruption to traffic and result in long-lived facilities.

To make these technologies standard, SHRP 2 is identifying innovative geotechnical solutions and developing new design guidelines, procedures, quality assurance and quality control test procedures, and performance-based construction specifications.

Bridge Design and Components

Durability is a problem for individual bridge components, such as bridge bearings, deck joints, and columns and piles. Joints and bearings are the leading maintenance costs for highway bridges. Currently, many bridge components are designed and constructed based on proven Ultimate Limit State (ULS) performance without regard for Service Limit States (SLS). In fact, in some cases, by focusing solely on ULS, performance at SLS may actually be less than optimal. Unfortunately, some of the most commonly used component details—such as bearings, joints, concrete cover, and structural steel coatings—may have inherent design flaws and limitations. Although many of the specific flaws are recognized, they have not been eliminated under current design procedures and specifications. And the environment and location in which these components are placed within a bridge often contribute to accelerated deterioration rates and reduced service life. This deterioration results in bridge components and systems that must be replaced frequently.

Tomorrow, bridge designers will have more options for reducing problematic bridge components. Designing bridge systems to deliver more than 100 years of service design life will be standard. Supplementary cementitious materials, such as pozzolans and slag, will be used to reduce chlorides permeating concrete. Improvements in steel-reinforced elastomeric bearing design will double their service life. Some bridges will incorporate improved joints into prefabricated bridge elements to increase service life. Other bridges will eliminate joints altogether or move the joints off the superstructure and into the roadway. Anticorrosion systems—such as corrosion-resistant reinforcing steel, admixtures, cathodic protection systems, and electrochemical chloride extraction—will be standard methods for protecting reinforced steel elements.

To help bring about this change, SHRP 2 research is improving existing systems, subsystems, and components that historically limit the service life of bridges. SHRP 2 is identifying and validating promising concepts for alternative systems, subsystems, and components that will have a service life of more than 100 years. SHRP 2 is also developing recommendations for load and resistance factor design and construction specifications. The models will include analysis methods, details, standard plans, and detailed design examples for bridge systems, subsystems, and components that can achieve more than 100 years of service life.

Bridge Construction

Traditional construction practices—such as erecting beams and framework, tying deck reinforcing steel, placing deck concrete, and allowing concrete to cure—are time-consuming and disruptive to traffic. Innovative design and construction solutions already exist to create new bridges and rapidly replace old bridges. These techniques make it possible to move large, prefabricated bridge elements or even major bridge systems. While total design and construction timeframes that do not affect traffic may remain significant, road closures may be limited to days or even hours using accelerated bridge construction (ABC) techniques.

Tomorrow, design concepts—such as precast abutments and piers, hybrid drilled shafts, segmental piers, complete composite steel superstructure systems, complete precast concrete superstructure systems, and space frame superstructures—will be standard. Ultra high-performance concrete (UHPC) will be used in joints. Using modern construction equipment—such as above-deck driven carrier systems, launched temporary truss bridges, wheel carriers, and self-propelled modular transporters (SPMTs)—to rapidly install bridges and bridge segments will also be standard. Standardizing these approaches will streamline the planning process. ABC Technology Test Cases 1 and 2 provide examples of how tomorrow's standards are used today.

To help turn today's innovations into tomorrow's standards, SHRP 2 is developing standardized approaches for designing, constructing, and reusing complete bridge systems that address rapid renewal needs and efficiently integrate modern construction equipment.

To showcase tomorrow's standards, SHRP 2 will conduct a field demonstration of ABC techniques in spring 2011. SHRP 2 is working in conjunction with the Iowa Department of Transportation to incorporate innovative bridge elements into a bridge located at US 6 over Keg Creek in Pottawattamie County, Iowa. While the original design for the bridge replacement would have required an estimated six-month road closure, the bridge replacement using ABC will limit road closures to two weeks. The demonstration, known as the Keg Creek Bridge Project, will showcase a prefabricated superstructure module (precast concrete deck on steel stringers), prefabricated substructure components (precast pier columns and caps and abutment stem and wing walls), and a prefabricated bridge approach (precast concrete panels and sleeper slab). This project will be the first in the United States to use UHPC to provide a full, moment-resisting transverse joint at the piers. A video of this demonstration will be posted on the SHRP 2 website.

Bridge Design Codes

Current calibrated ULS approaches cannot integrate the daily, seasonal, and long-term SLS stresses that will directly

affect long-term performance. New design codes are needed that incorporate a rational approach based on SLS for durability and performance of problematic systems, subsystems, components, and details. This is in addition to traditional structural design within the framework of the current AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications.

Tomorrow, design codes will help bridges achieve more than 100 years of service life. Design codes will include a rational approach based on SLS for durability and performance of bridge systems, subsystems, components, and details that are critical to reaching the expected service life. Performance measures will incorporate predefined component classifications that utilize probability-based service life design criteria to help maximize the actual life of the system. Durability design and structural design will be incorporated into design procedures and specifications.

To help make tomorrow's design codes, SHRP 2 is developing bridge design procedures and proposed specification changes that include durability design in addition to structural design, as well as developing the tools required for SLS implementation. The design procedures and specifications will include information from data sets being developed and captured by national and local initiatives into new or revised design specifications.

Evaluating Bridge Decks

It is estimated that more than $1 billion is spent on bridge decks each year in the United States. Since nearly 90 percent of bridge deck area (2.8 billion square feet) is concrete, evaluating concrete bridge decks is essential. Highway agencies need to evaluate bridge deck condition in order to optimize the effective timing of preventive maintenance, prioritize bridge deck repair and rehabilitation, determine the scope of required repairs, and make repair-or-replace decisions. Deck deterioration frequently takes place below the surface and cannot be readily evaluated by visual means, and many older decks now have asphalt concrete or portland cement concrete overlays, making subsurface deterioration conditions even more difficult to detect. Traditional deck inspection methods—such as chain drag, half-cell potentials, and chloride content—are slow, require closures, and are not necessarily effective. Over the past 10 years, innovative higher-speed nondestructive testing (NDT) technologies have been developed. These technologies, however, have not been widely adapted or accepted for three main reasons: (1) Even though a number of technologies can provide detailed and accurate information about a certain type of deterioration or defect, comprehensive condition assessment of bridge decks, at this stage, can be achieved only by using multiple technologies. (2) Speed remains a major limitation for most of the technologies and is a main inhibitor for wide adoption by transportation agencies. There are a number of initiatives to speed up the data collection and automate data analysis, but those initiatives are fragmented and still do not provide a transformational change towards comprehensive, multimodal, and rapid bridge deck evaluation. (3) Most of the technologies require a significant level of training and expertise, especially in the data analysis and interpretation components.

Tomorrow, expect NDT technologies to be a standard part of concrete bridge deck evaluation. Impact echo

ABC Construction Technology Test Case 1
Springboro, Ohio, Access Bridge

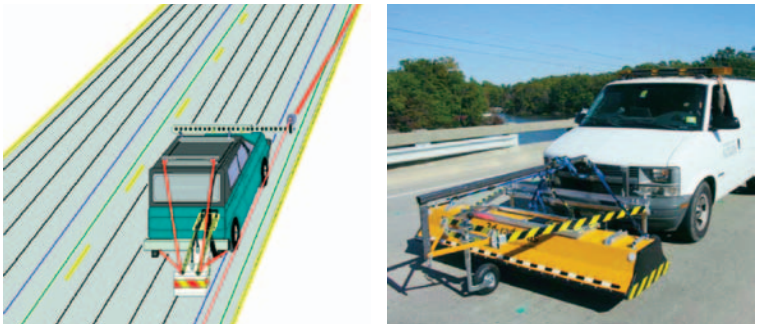
Project Type	Bridge Replacement
Project Description	Remove existing simple span bridge and replace with new, wider bridge with equal span length
Structure Type	Existing Bridge—Steel girder with timber plank deck New Bridge—Precast concrete girders and precast deck with cast-in-place closure joints

The project was completed within 56 hours even with a significant period of rain after the old bridge had been removed. New piles were driven before the bridge was removed. With the short span of the bridge, there was no need for special equipment so conventional construction equipment was used. Due to the tight schedule, ABC superstructure and substructure technologies such as precast abutments, precast girders, and precast deck panels were used.

ABC Construction Technology Test Case 2
Utah State Road 4500S over I-215E

Project Type	Bridge Replacement
Project Description	Bridge replacement with minimal disruption to traffic both on main line and secondary road
Structure Type	Existing Bridge—Precast Girders, Concrete Deck New Bridge—Precast Girders, Concrete Deck

The project was performed using SPMTs for both the removal of the existing bridge and installation of the new bridge. I-215E was closed for 53 hours over a weekend and 4500S was closed only 10 days.



Typical GPR survey of a bridge deck using a set of dual-polarization sensors requiring six passes of the survey vehicle in each lane (left) and a 2 meter-wide 3D-GPR array system (right), which operates more slowly but covers a larger deck width.

techniques will be used for detecting and characterizing deck delamination, investigating crack depth, and evaluating grouting condition in ducts. Ultrasonic pulse echo techniques and pulse velocity techniques will be used for detecting voids, grouting condition in ducts, material degradation, and other anomalies. Ultrasonic surface waves will be used to measure degradation of mechanical properties, such as modulus and strength. Impact response techniques will be used to detect deck delaminations. Ground-penetrating radar (GPR) will be used to detect deterioration caused by corrosion, indirect delamination, voids, anomalies in concrete, water-filled or epoxy-injected cracks, and debonded overlays. And infrared thermography will be used to detect overlay debonding, delamination, presence of moisture, and near-surface voids.

To bring these innovations into the mainstream, SHRP 2 is identifying, characterizing, and validating rapid NDT technologies for concrete deck deterioration to create an electronic repository, or tool box, for practitioners. This process includes evaluating the strengths and limitations of NDT technologies in terms of speed, accuracy, precision, and ease of use. The repository is being designed so that it could be incorporated into transportation agencies' inspection manuals or management systems. The repository will include documentation for test procedures, protocols, photos, sample data output, equipment features (such as cost, availability, and specifications), advantages, and limitations.

SHRP 2 Bridge Projects

R02	Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform
R04	Innovative Bridge Designs for Rapid Renewal
R04A	Innovative Bridge Designs for Rapid Renewal (Keg Creek Bridge Demonstration Project)
R06A	Nondestructive Testing to Identify Concrete Bridge Deck Deterioration
R19A	Bridges for Service Life beyond 100 Years: Innovative Systems, Subsystems, and Components
R19B	Bridges for Service Life beyond 100 Years: Service Limit State Design

Tomorrow

Tomorrow's bridges will be built on more stable foundations. They will be created rapidly. Testing the bridge decks will be quick and easy. And the bridges will be in service for more than 100 years.

The SHRP 2 Bridge Projects Chart shows the SHRP 2 projects that are turning today's bridge innovations into tomorrow's standards. But you don't have to wait until tomorrow to find out about these innovations. You can stay ahead of the curve by following SHRP 2 research. Learn more on the SHRP 2 website: www.TRB.org/SHRP2. While there, you can also subscribe to SHRP 2 News to receive e-mail alerts about our reports, guides, webinars, conferences, videos, and more.

These bridge projects are part of SHRP 2's Renewal research. The research objective of SHRP 2 highway renewal is to achieve renewal that is performed rapidly, causes minimum disruption, and produces long-lived facilities. A related objective is to achieve such renewal not just on isolated, high-profile projects, but consistently throughout the nation's highway system.

A Renewal Project Brief

A Toolkit for Accelerated Bridge Construction

JUNE 2013

Accelerated bridge construction (ABC) techniques have the potential to minimize traffic disruptions during bridge renewals, promote traffic and worker safety, and also improve the overall quality and durability of bridges. Typical construct-in-place processes—such as erecting beams, erecting formwork, tying deck reinforcing steel, placing deck concrete, and allowing concrete to cure—are time consuming; these and other sequential onsite construction activities can disrupt traffic and degrade highway safety. Because ABC entails prefabricating as many bridge components as feasible, it minimizes road closures and traffic disruptions, both goals of rapid renewal techniques.

ABC applications in the United States have developed two different approaches: accelerated construction of bridges in place using prefabricated systems, and the use of bridge movement technology to move completed bridges from an off-alignment location into the final position. Despite the gradual lowering of costs, transportation agencies are hesitant about using ABC techniques because of their perceived risks and higher initial costs. Rather than custom engineering every solution, pre-engineered modular systems configured for traditional construction equipment could promote more widespread use of ABC through reduced costs and increased familiarity with these systems among owners, contractors, and designers.

This document gives an overview of SHRP 2 Project R04: Innovative Bridge Designs for Rapid Renewal, which developed standardized approaches to designing and constructing complete bridge systems. This project created the SHRP 2 ABC Toolkit, which includes recommended design standards and design examples for complete prefabricated bridge systems for routine bridges with span lengths from 40 ft to 130 ft. The Toolkit also includes recommended specification language for ABC systems for future inclusion in the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design and Construction Specifications. The ABC design standards developed in this project were used in pilot projects in Iowa, New York, and Vermont.

Strategies for Accelerated Bridge Construction

For ABC to be successful, ABC designs should allow maximum opportunities for the general contractor to carry out prefabrication and erection. This project focused on three specific strategies for ABC systems:

1. Bridge should be as light as possible
    a. Sized to be manageable for transportation and installation
    b. Simplifies transportation and erection of bridge components
    c. Could improve the load rating of existing piers/foundations

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2. Bridge should be as simple as possible
    a. Fewer girders
    b. Fewer field splices
    c. Fewer bracing systems
    d. No temporary bracing to be removed
3. Bridge should be as simple to erect as possible
    a. Fewer workers on site
    b. Fewer cast-in-place operations
    c. No false-work structures required for prefabricated elements and systems
    d. Simpler geometry

This project classified ABC design concepts into five tiers, based on implementation duration:

- Tier 1: Traffic Impacts within 1 to 24 hours
- Tier 2: Traffic Impacts within 3 days
- Tier 3: Traffic Impacts within 2 weeks
- Tier 4: Traffic Impacts within 3 months
- Tier 5: Overall project schedule is significantly reduced by months to years

Modular bridge systems are particularly suited to be used as a Tier 2 concept for weekend bridge replacements or as a Tier 3 concept, in which the entire bridge may be scheduled to be replaced within one to two weeks using a detour to maintain traffic. Tier 1 concepts include preassembled superstructures, completed at an off-alignment location and then moved via various methods into the final location using techniques such as lateral sliding, rolling, and skidding; incremental launching; and movement and placement using self-propelled modular transporters. Tier 5 involves accelerating a statewide bridge renewal program by months or years through application of ABC technologies in the other tiers.

Standardized Designs

This project identified impediments and obstacles to greater use of ABC (through focus group meetings and surveys) and developed solutions to overcome them. Despite the gradual lowering of costs and the life-cycle cost savings, bridge owners are hesitant to use ABC techniques because of their higher initial costs and perceived risks. Another impediment to the rapid delivery of projects is the slow engineering process of custom engineering every solution. However, pre-engineered modular systems configured for conventional construction equipment could promote more widespread use of ABC through reduced costs and increased familiarity with these systems among owners, contractors, and designers.

Standardized designs geared for conventional crane-based erection would allow for repetitive use of modular superstructure systems, which could make contractors more willing to invest in equipment based on certain methods of erection to speed assembly. Repetitive use would allow contractors to amortize equipment costs over several projects, which is an important component to bring overall costs in line with cast-in-place construction. Where site condition makes crane-based erection difficult, overhead erection using ABC construction technologies provide an attractive alternative. Both of these options are addressed in the recommended ABC standards.

Typical ABC details for superstructure and substructure systems for routine bridges that are suitable for a range of spans are included in the Toolkit. Bridge designers are well versed in sizing beams and designing reinforcing steel for conventional construction for a specific site, and it would be appropriate for the engineer of record (EOR) to perform these functions for ABC projects as well. A single set of ABC designs for national use would not be practical as there are state-specific modifications to LRFD bridge design specifications, including loads, design permit vehicle for Strength II, and performance criteria for service limit states. The EOR, guided by the standard concepts and details and the accompanying set of ABC sample design calculations, would be able to easily complete an ABC design for a routine bridge replacement project. The standard concepts would need to be customized by the EOR to fit the specific site in terms of the bridge geometry, span configuration, member sizes, and foundations. The overall configurations of the modules, their assembly, connection, tolerances, and finishing would remain unchanged from site to site. The ABC designs should also be reviewed for compliance with state-specific LRFD design criteria.

The standard concepts provide substantially complete details pertaining to the ABC aspects of the project. Much of the remaining work in preparing design plans is not particularly related to ABC, but to bridge and site-specific customization. Specific instructions to designers are covered through general information sheets, plan notes, and instructions so that all the key design and construction issues in ABC projects are adequately addressed. The standard concepts, used in conjunction with the ABC sample design calculations and design specifications, will help designers become accustomed to ABC. More information about standardized designs is in the final report.

SHRP 2 ABC Toolkit Overview

This project developed pre-engineered designs to optimize modular construction and ABC. In addition to fostering more widespread use of ABC, standardizing ABC systems can result in greater familiarity with ABC technologies and concepts. The SHRP 2 ABC Toolkit includes the following components:

1. ABC standard concepts (as both PDF and CADD files),
2. ABC sample design calculations (as both PDF and mathcad files),

3. Recommended ABC design specifications (in LRFD format), and
4. Recommended ABC construction specifications (in LRFD format).

This Toolkit is not meant to be a comprehensive manual on all aspects of ABC. It is focused on the design and assembly of routine bridges using ABC techniques that would be of value to engineers, owners, and contractors new to ABC. It complements other publications on ABC, including the final report on this project, which should be consulted for more specific information on topics outside the scope of the Toolkit.

ABC Standard Concepts

Standard concepts were developed for the most useful technologies that can be deployed on a large scale in bridge replacement applications. They include complete prefabricated modular systems and construction technologies as outlined below:

- Precast modular abutment systems
  - Integral abutments
  - Semi-integral abutments
  - Precast approach slabs
- Precast complete pier systems
  - Conventional pier bents
  - Straddle pier bents
- Modular superstructure systems
  - Decked steel stringer system
  - Concrete deck bulb tees
  - Concrete deck double tees
- ABC bridge erection systems
  - Erection using cranes
  - Above-deck driven carriers
  - Launched temporary truss bridge

ABC Sample Design Calculations

Detailed sample design calculations provide step-by-step guidance on the overall structural design of the prefabricated bridge elements and systems for design engineers. The sample design calculations pertain to the same standard bridge configurations for steel and concrete used in the ABC standard concepts. The intent was to provide sample design calculations that could be used in conjunction with the ABC standard concepts so that practitioners new to ABC would get a comprehensive look at how ABC designs are carried out and translated into design drawings and details.

Recommended ABC Design Specifications

LRFD bridge design specifications do not deal explicitly with the unique aspects of large-scale prefabrication including issues such as element interconnection, system strength, and behavior of rapid deployment systems during construction. This project identified shortcomings in the current LRFD bridge design specifications that may be limiting their use for ABC designs and made recommendations for addressing these limitations. Recommended LRFD specifications for ABC bridge design are also included in the Toolkit. Users should note that these recommendations have not yet been formally adopted by AASHTO.

Iowa DOT/HNTB for SHRP 2

Keg Creek Bridge Project

Recommended ABC Construction Specifications

Recommended LRFD construction specifications for prefabricated elements and modular systems include best practices that are to be used in conjunction with the standard concepts for steel and concrete modular systems. As such, these specifications for rapid replacement focus heavily on means and methods requirements for rapid construction using prefabricated modular systems.

Keg Creek Bridge Project

In fall 2011, the designs and construction concepts developed as part of this research project were demonstrated during the replacement of a bridge located on US 6 over Keg Creek in Pottawattamie County, Iowa. The research agency for this project, in collaboration with the Iowa Department of Transportation (DOT), developed detailed bridge plans, details, and specifications that were incorporated into the construction of the replacement bridge. The replacement bridge, completed in 14 days, showcases the following innovative elements:

- Prefabricated superstructure module (precast concrete deck on steel stringers),
- Prefabricated substructure components (precast pier columns and caps and abutment stem and wing walls), and
- Prefabricated bridge approach (precast concrete panels and sleeper slab).

Wendell Davis/FEMA

One of the many bridges in Vermont destroyed by Tropical Storm Irene

To document this demonstration, three videos were produced: a 90-second time-lapse video of the construction, a 10-minute video overview of the project, and a 19-minute video that highlights the specific techniques used.

Iowa DOT's collaboration with SHRP 2 on this project won the America's Transportation Awards competition in the category of Best Use of Innovation award for a small project, which celebrates excellence in innovative management techniques and use of technology. The America's Transportation Awards competition—which is sponsored by AASHTO, AAA, and the U.S. Chamber of Commerce—recognizes the best transportation projects by state departments of transportation in three categories: Best Use of Innovation, Under Budget, and Ahead of Schedule.

Toolkit in Action

Following Iowa's success with the Keg Creek project, two other states made plans to use the SHRP 2 ABC Toolkit.

After Tropical Storm Irene washed out more than 2,000 roads and damaged hundreds of bridges in Vermont, the Vermont Department of Transportation (VTrans) looked to SHRP 2 for help. VTrans is using the SHRP 2 ABC Toolkit to replace 17 bridges. The projects are using precast NEXT beams on precast abutments on steel H-piles with precast approach slabs. Vtrans adapted the SHRP 2 ABC Toolkit to suit its practices. The first four bridges were the Hancock Bridge on VT 125, the Warrant and Jamaica bridges on VT 100, and the Brighton Bridge on VT 105. The additional bridges are in project development.

The New York State Department of Transportation is using the SHRP 2 ABC Toolkit to replace the eastbound and westbound I-84 bridges over Dingle Ridge Road using lateral slide technology. The existing structure is a 135 ft three-span steel girder superstructure. The replacement bridges will use modular double-tee NEXT beams joined with UHPC closure pours. This project is currently under construction and the lateral slide will be completed over two weekends in September 2013—one closure for each bridge. Whereas a conventional bridge replacement would have added two years to the timeframe and $2 million in additional costs, these innovative ABC techniques will eliminate the need for a temporary bridge, minimize traffic impact, improve safety, and minimize environmental impacts to the New York City watershed area.

Status

This project will be completed in December 2013. The videos from the Keg Creek Demonstration are available at www.TRB.org/SHRP2/KegCreek. The final report is available at http://www.trb.org/Main/Blurbs/167693.aspx and the Toolkit is available at http://www.trb.org/Main/Blurbs/168046.aspx. A supplement to the toolkit will be published based on the results of the Vermont and New York Pilots. Videos of those pilot projects will also be made available in late 2013.

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A SHRP 2 Renewal Project Brief

Designing Bridges for Service Life

AUGUST 2013

Addressing service life during bridge design has the potential to significantly reduce the costs and risks that are associated with bridge maintenance and preservation activities. A systematic approach to designing bridges and their elements, components, systems, and subsystems for service life provides an array of options that can enhance service life and optimize the timing of interventions.

Design Guide for Bridges for Service Life (the Guide) was produced in Bridges for Service Life beyond 100 Years: Innovative Systems, Subsystems, and Components (SHRP 2 Project R19A). The main objective of the Guide is to provide information and define procedures for systematically designing for service life and durability for both new and existing bridges. It includes new concepts and approaches that offer improvements to current practice and have the potential to enhance the service life of bridges. The Guide is intended to equip users with the knowledge needed to develop specific optimal solutions for a bridge. The Guide's approach to designing for service life is based on a framework, outlined in 12 steps, that is applicable to all bridges and adaptable to specifics that vary from bridge to bridge. This project brief provides an overview of the Guide and its 12 steps.

Bridge Service Life-Related Terminology and Relationships

- **Service Life.** The time period during which the bridge element, component, subsystem, or system provides the desired level of performance or functionality, with any required level of repair and maintenance.
- **Target Design Service Life.** The time period during which the bridge element, component, subsystem, or system is expected to provide the desired function with a specified level of maintenance established at the design or retrofit stage.
- **Design Life.** The period of time on which the statistical derivation of transient loads is based—75 years according to the 2012 edition of *AASHTO LRFD Bridge Design Specifications,* hereafter referred to as Load and Resistance Factor Design (LRFD) Specifications.
- **Bridge Element.** Individual bridge members—including girder, floor beam, stringer, cap, bearing, expansion joint, and railing. When combined, these elements form subsystems and components, which together constitute a bridge system.
- **Bridge Component.** A combination of bridge elements forming one of the three major portions of a bridge that comprises the entire structure—substructure, superstructure, and deck.
- **Bridge Subsystem.** A combination of two or more bridge elements acting together to serve a common structural purpose. Examples include composite girder, which could consist of girder, reinforcement, and concrete.
- **Bridge System.** The three major components of the bridge—deck, substructure, and superstructure—combined to form a complete bridge.

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Several basic relationships exist between bridge design life and the service lives of bridge components, elements, subsystems, and systems:

- Predicting the service life of bridge systems is accomplished by predicting the service life of its elements, components, or subsystems.
- The design life of a bridge system is a target life in years, set at the initial design stage, and specified by the bridge owner.
- The service life of a given bridge element, component, subsystem, or system could be more than the target design service life of the bridge system.
- The end of service life for a bridge element, component, or subsystem does not necessarily signify the end of bridge system service life as long as the bridge element, component, or subsystem could be replaced or resume its function with retrofit.
- A given bridge element, component, or subsystem could be replaced or retrofitted, allowing the bridge as a system to continue providing the desired function.
- The service life of a bridge element, component, or subsystem ends when it is no longer economical or feasible to undergo repairs or retrofits, and replacement is the only remaining option.
- The service life of a bridge system ends when it is not possible to replace or retrofit one or more of its components, elements, or subsystems economically or because of other considerations.
- The service life of a bridge system is governed by the service life of its critical elements, components, and subsystems. The critical bridge elements, components, or subsystems are defined as those needed for the bridge as a system to provide its intended function.

Guide Approach to Design for Service Life

The Guide's approach to design for service life is to provide a body of knowledge relating to bridge durability under different exposure conditions and constraints, and to establish an array of options capable of enhancing service life. A solution for a particular service life issue is highly dependent on many factors that vary from location to location and state to state, because a solution depends on local practices and preferences. Consequently, use of the Guide is not intended to dictate a unique solution for any specific service life problem or to identify the "best and only" solution. Rather, it equips the reader with a body of knowledge for developing specific solutions best suited to stated conditions and constraints.

When applying the Guide framework to a particular bridge, including long-span bridges, an array of solutions can be identified for enhancing the service life of a bridge element, component, or subsystem, and an optimum solution can be identified through life-cycle cost analysis. The solutions can be based on data collected by local transportation agencies responsible for maintaining the bridge, and in order to be complete, the life-cycle cost analysis should include maintenance, retrofit, replacement, and user costs. It is important that the list of assumptions and feasible solutions considered for a particular bridge element, component, and subsystem be communicated and shared with the owner, especially with respect to the life-cycle cost analysis, so that the entire process is fully transparent.

The Guide recognizes that not all bridges can or need to have 100 years of service life. Therefore maintenance, rehabilitation, and replacement are part of the service life design process. The Guide provides the general framework to achieve this objective through a systematic approach that considers the entire bridge system and all project demands.

There are different methods of enhancing the service life of existing and new bridges. Examples include a) using improved, more durable materials and systems during original construction that will require minimal maintenance; and b) improving techniques and optimizing the timing of interventions, such as preventive maintenance actions. Interventions can be planned and carried out based on the assessment of individual bridge conditions and needs, or based on a program of preventive maintenance actions planned for similar elements on a group of bridges. A simple example of a preventive, planned maintenance program might include the following activities:

- Spot painting steel structures
- Sealing decks or superstructures in marine environments
- Sealing substructures on overpasses where deicing salts are used on the roadways below
- Washing deicing salts off bridge decks in the spring
- Cleaning debris from bridge deck expansion joints
- Cleaning debris from bearings and truss joints
- Cleaning drainage outlets

By acknowledging that service life can be extended either by using more durable, deterioration-resistant materials or by planned intervention, a cost comparison can be made to determine the most cost-effective approach for various environmental exposure levels and various levels of available maintenance and preservation actions.

12 Steps to Design Bridges for Service Life

The following section provides an overview of the general approach used in the Guide. The 12 steps were created for new bridges; however, the Guide's approach can be

adapted for existing bridges by eliminating some of the steps. Because the descriptions are general and use very simple examples to demonstrate the point of discussion, many intermediate steps are eliminated for the sake of clarity.

Step 1

The design for service life begins by first considering all project demands set by the owner, including the service life requirements. The Guide provides examples of local operational and site requirements, as well as service life considerations that need attention.

Step 2

Develop all feasible and preliminary bridge alternatives that satisfy project demands. For example, one might want to consider steel, concrete, and segmental bridge alternates for a particular bridge. The development of the potential bridge systems is carried out in a conventional manner, meeting all the provisions of the LRFD Specifications. It is good practice to consider potential service life issues, even at this stage of the design process. It is also feasible to use bridge technologies that do not have a specific design guideline within the LRFD Specifications. In such cases, the best available design approach could be used, subject to owner approval.

Steps 3 and 4

Evaluate each bridge system alternate one at a time, considering service life issues related to each element, component, and subsystem of that bridge system. For each bridge element, component, and subsystem, the Guide provides a framework for incorporating the changes and modifications needed to meet service life requirements.

For example, assume that one of the bridge systems to be considered for a particular project is a steel bridge alternate. The designer will first develop the preliminary bridge configurations using the conventional approaches that meet all LRFD specifications. Then each element, component, or subsystem of the steel alternate will be checked against the service life requirements using the fault tree approach described in the Guide. An example of a fault tree can be seen in Figure 1. These evaluation requirements may lead to changes in the details of the element, component, or subsystem under consideration. For example, the preliminary deck configuration may indicate that use of 8-in. thick concrete is sufficient from a strength standpoint. Going through the fault tree corresponding to bridge deck, the designer may change the deck thickness to 9 in. to address potential overloads, or may specify sealing the bottom of the deck to protect it from salt spray if the bridge is located along the coastline. It should be noted that for major and complex bridges, most of these fault trees will need to be customized to meet specific needs and preferred practices. Examples of fault trees and how they work are provided in the Guide.

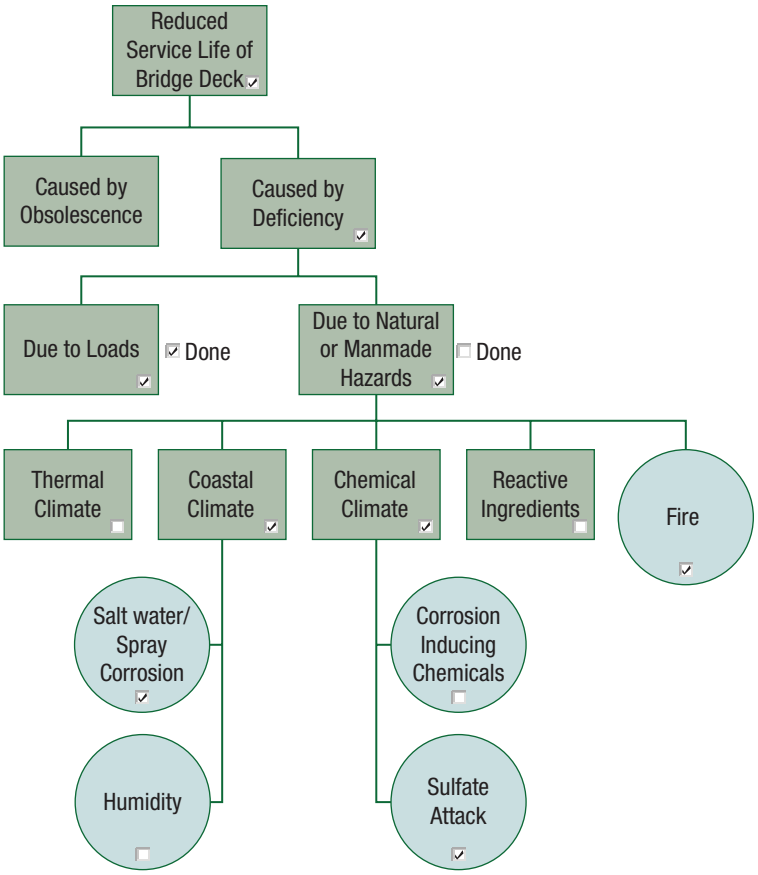
Table 1. 12 Steps to Design Bridges for Service Life

Step 1.	Identify the project requirements, particularly those that will influence the service life.
Step 2.	Identify feasible bridge systems capable of meeting the project demand.
Step 3.	Select each feasible bridge system and complete Steps 4 through 10.
Step 4.	Identify the factors that influence service life of bridge elements, components, and subsystems, such as traffic and environmental factors.
Step 5.	Identify modes of failures and consequences. For instance, the corrosion of reinforcement causing corrosion-induced cracking and loss of strength.
Step 6.	Identify suitable approaches for mitigating the failure modes or assessing risk of damage, through life-cycle cost analysis. For example, use better-performing materials for sliding surfaces in bearings.
Step 7.	Modify the element, component, or subsystem under consideration, using the selected strategy and ensure compatibility of different strategies used for various bridge elements, components, or subsystems. This step may involve the need to develop several alternatives.
Step 8.	For each modified alternative, estimate the service life of the bridge element, component, or subsystem using finite or target service life design approaches.
Step 9.	For each modified alternative, compare the service life of the bridge element, component, or subsystem to the service life of the bridge system and develop appropriate maintenance, retrofit, and/or replacement plan.
Step 10.	For each modified alternative, develop design, fabrication, construction, operation, maintenance, replacement, and management plans for achieving the specified design life for the bridge system.
Step 11.	For each modified alternative, conduct life-cycle cost analysis for each feasible bridge system meeting strength and service life requirements, and select the optimum bridge system.
Step 12.	When specified by the owner or in cases of major and complex bridges, document the entire design for service life process in a document called the Owner's Manual. Conduct an independent review of the document and provide it to the bridge owner at the time of opening the bridge to traffic.

Steps 5 through 8

At the end of Step 4 and after going through appropriate fault trees for various bridge elements, components, and subsystems, the designer will have developed a bridge system that meets both strength and service life requirements. To some extent, changes to configurations of various bridge elements, components, and subsystems are carried out separately. However, there is a need to ensure that these changes are compatible and not contradictory or overly conservative, and that is what happens in steps 6 and 7. For example, in the steel bridge example discussed previously, service life requirements may dictate the use of a jointless, integral abutment system and require metalizing the end of the girder. The designer may then want to consider not metalizing the end of the girder, since leaking joints would be eliminated. In Step 8 the designer develops

Figure 1. Example Segment of the Fault Tree.



a final configuration for the selected bridge system alternate under consideration that meets both strength and service life requirements.

Steps 9 through 12

In Step 9, the designer will evaluate the service life of the various bridge elements, components, and subsystems of the bridge alternate under consideration and compare it to the owner-specified target service design life of the bridge system. For example, the owner may require that the bridge provide 100 years of service life, whereas the life of a particular bridge element, such as the sliding surface for a bearing, may be limited to 20 years. This would require the designer to determine how to accommodate replacement of the sliding surfaces. This would also require the designer to develop a systematic maintenance plan that could include the identification of "hot areas" requiring more detailed inspection and maintenance. By Step 10, the designer should have a bridge system alternate that meets both strength and service life requirements with an associated maintenance and/or rehabilitation or replacement plan for the bridge. In Step 10 the designer has to carry out life-cycle cost analysis, considering the final configuration of the select bridge alternate and maintenance plan. The same steps are repeated for all bridge alternate systems in Step 11. After comparing all alternates, the designer can then recommend which alternate should be used, allowing the owner to make the final selection.

When specified by the owner or in cases of major and complex bridges, Step 12 requires the designer to document the entire design for service life processes in a document called the Owner's Manual. The designer would also conduct an independent review of the document and provide it to bridge owner at the time of opening the bridge to traffic.

Status

This project is complete. Design Guide for Bridges for Service Life is available at http://www.trb.org/Main/Blurbs/168760.aspx. The research report will be available on the TRB website in fall 2013.

A SHRP 2 Renewal Project Brief

Nondestructive Testing Technologies for Rapid Renewal

Reduce Traffic Disruptions, Improve Efficiency

OCTOBER 2012

Many nondestructive testing (NDT) and nondestructive evaluation (NDE) techniques have the potential to inspect new construction and test existing infrastructure much faster than typical methods.

To advance the state of practice, SHRP 2 conducted a series of projects to improve existing NDT and NDE techniques. The products of this research include tools to help practitioners (a) test concrete bridge decks, (b) perform quality control of construction materials, (c) conduct uniformity measurements on new hot-mix asphalt layers, (d) detect debonding and stripping between hot-mix asphalt layers, (e) detect surface irregularities during concrete paving operations, (f) measure the structural capacity of pavement while minimizing traffic disruptions, and (g) quickly monitor the condition and deterioration of tunnel linings. This Project Brief gives an overview of advances in seven methods to help transportation agencies meet rapid renewal goals.

A Plan for Nondestructive Testing

The first SHRP 2 project in the field of NDT and NDE evaluated the existing and emerging NDE technologies and their ability to satisfy NDE requirements for rapid highway renewal. Based on the findings of this project, a research plan was devised for developing technologies to deal with the most pertinent requirements for bridges, pavements, tunnels, soils, and retaining walls through the life of the facility. The resulting seven follow-on projects are described in this brief.

Status: This project is complete. *A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection* (SHRP 2 Report S2-R06-RW) is available on the SHRP 2 website.
SHRP 2 Contact: Monica Starnes, mstarnes@nas.edu

Nondestructive Testing for Concrete Bridge Decks

The number of concrete bridge decks in poor structural condition is one of the biggest problems affecting bridges in the United States. Evaluating bridge deck condition becomes increasingly critical as highway agencies work to optimize the effective timing, scope, and approaches for preventive maintenance, repair, and replacement. NDT techniques have the potential to quickly and reliably provide the needed information about under-the-surface conditions of the deck, but further advances, standard protocols, and independent evaluations are needed.

The research objective of this project was to conduct an independent evaluation of the capabilities and limitations of the most common NDT techniques to detect and characterize typical deterioration mechanisms in concrete bridge decks. The following four defects were identified as those of the highest importance: rebar corrosion, delamination, vertical cracking, and concrete degradation.

This project created an electronic repository of NDT technologies for bridge decks, known as the NDToolbox, with which users can explore different NDT technologies and examine their

Field evaluation of an impulse response testing device

application in the detection of deterioration. The information in the NDToolbox includes a description of the technology, the principle behind the technology, applications, performance, limitations, equipment, test procedures and protocols, and sample results. The NDToolbox also provides recommendations regarding the best technologies for a particular deterioration detection application. Additional tasks were recently added to this project to expand the coverage of the NDToolbox. Once completed, the NDToolbox will include the results from all NDT research projects under SHRP 2; at that point the NDToolbox could serve as a quick reference of validated methods for identifying deterioration on concrete bridge decks, as well as those for quality control of construction materials and pavements, and condition assessment of pavements and tunnels.

Status: Project R06A (Nondestructive Testing to Identify Concrete Bridge Deck Deterioration) is active. Videos of a field validation of the technologies are available at www.TRB.org/SHRP2/Videos. The final report will be available in 2013. The NDToolbox will also be available in 2013.
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Quality Control of Construction Materials

Quality control of materials used during construction is an important issue routinely affecting highway agencies across the United States. Evaluating whether the materials delivered at the construction site agree with those specified can be resolved by existing testing techniques. Using hand-held spectroscopic equipment in the field, rather than traditional chemical tests, for testing the quality assurance of many materials (including cements, paints, and asphalt mixtures) can yield faster measurements.

Portable spectroscopy devices and their capabilities to "fingerprint" typical construction materials were evaluated by this project. Fingerprinting of typical materials requires developing acceptable spectra of the specific chemical compositions with laboratory-based equipment and then comparing the material being fingerprinted against those spectra. Additional tasks were recently added that will develop specifications and pilot them in collaboration with two transportation agencies.

Products from this research include proposed American Association of State Highway and Transportation Officials (AASHTO) standards of practice for the analysis of titanium content in traffic paints by X-ray florescence (XRF) and identification of cement admixtures and RAP-modified asphalt by attenuated total reflectance (ATR), and field operation manuals for ATR and XRF instruments. The library of spectra for the tested materials can be used to identify these materials in the field. The proposed AASHTO standards will be useful to quality assurance and quality control personnel and research and material divisions in transportation agencies. The field operation manuals were developed for ATR and XRF instruments to supplement the standards. These manuals will be useful to field personnel who will conduct spectroscopic testing; however, the variability in the available instruments requires that the specific technical manual for each instrument should also be consulted.

Status: Project R06B (Evaluating Applications of Field Spectroscopy Devices to Fingerprint Commonly Used Construction Materials) is active. The final report will be published in 2013.
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Mitigate Segregation in Hot-Mix Asphalt Construction

The most common form of hot-mix asphalt (HMA) segregation, truck-end, occurs when HMA at the ends of the truckload is colder and sometimes coarser in gradation than normal. These segregated locations deteriorate early, typically due to their lower density and higher susceptibility to raveling and fatigue cracking. This early distress not only results in poorer ride quality but also requires agencies to use resources earlier than planned to maintain the pavement condition.

An automated thermal profiling system offers a means for passive inspection. Using these technologies can produce higher-quality, longer-lasting new HMA pavements.

This project summarized the availability of infrared and radar systems suitable for testing essentially the entire surface area during new HMA construction, and then it demonstrated an infrared sensor bar system and two ground-penetrating radar (GPR) systems on construction projects in each of the four AASHTO regions.

Products include recommendations for equipment and testing protocols for using infrared and GPR for testing the entire surface area during new HMA construction.

The thermal profiling system can provide a real-time view of thermal uniformity. This infrared system is now commercially available and can be implemented into agency specifications. The GPR systems are suitable for evaluating pavement uniformity and, in general, can detect low-density defect areas in new overlays; however, streamlining of the data collection and processing needs to take place before GPR can be widely implemented and incorporated into specifications. A framework was developed for automating the GPR process to achieve an implementable system.

Status: SHRP 2 Project R06C (Using Both Infrared and High-Speed Ground-Penetrating Radar for Uniformity Measurements on New HMA Layers) is active. A video showing a demonstration of the infrared system is available at www.TRB.org/SHRP2/Videos. The final report will be published in 2013.
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Detect Debonding and Stripping in Hot-Mix Asphalt

Several types of surface distress in pavements can be attributed to delamination in HMA layers, including longitudinal cracking in the wheel path and tearing in the surface. HMA delamination is primarily due to layer debonding or stripping. Debonding occurs when there is imperfect tack between paved HMA layers or between an HMA overlay and concrete pavement; stripping develops when the aggregates and asphalt binder are incompatible, adhesion is lost, and water separates the asphalt binder from the aggregate. The distress (cracking or tearing) is the first indication that delamination may be occurring within the pavement layers. A test method is needed to detect the location and severity of delamination before the pavement deficiency causes visual pavement distress.

This project evaluated the capability of NDT technologies to detect the extent, depth, and severity of delamination in HMA pavements. The technologies that were evaluated include GPR, infrared thermography, mechanical waves, and deflectometers.

Technical briefs and details were developed for NDT technologies that can identify delaminations, namely GPR (which uses an air-launched antenna array with frequency sweep measurements) and a scanning mechanical wave system (which measures impact echo and spectral analysis of surface waves). Both systems are ready for project-level use but need more data analysis software for network-level assessment.

Status: SHRP 2 Project R06D (Nondestructive Testing to Identify Delaminations between HMA Layers) is active. The final report will be published in 2013.
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Detect Surface Irregularities on Portland Cement Concrete Pavements during Construction

Most states have implemented smoothness specifications for concrete pavements. These specifications require measurements of surface profile on the finished pavement for acceptance testing. Because of this, smoothness measurements are not made until after the concrete has hardened and problems are not corrected in real time, resulting in significant expenditures to correct surface irregularities. There is a need for further development of a construction quality-control tool for detecting surface irregularities during concrete paving operations. With this information, deviations could be detected in real time and corrections could be made.

This project evaluated and conducted demonstrations of both emerging and proven technologies. Based on those results, the project developed model specifications and construction guidance to expedite the implementation of technologies that can provide an indication of smoothness in real time. In this project, of the seven potential measurement devices identified and studied, two warranted subsequent evaluation and demonstration: (1) the GOMACO Smoothness Indicator and (2) the Ames Engineering Real-Time Profiler. Field tests found that these technologies have (a) reasonable agreement to reference profiles, (b) ability to provide a relative estimate of roughness, and (c) ability to recognize areas where roughness accumulates the most aggressively—that is, localized roughness. It should be noted that these technologies do not measure the smoothness of hardened concrete directly; they identify areas where the relative smoothness is affected.

Status: SHRP 2 Project R06E (Real-Time Smoothness Measurements on Portland Cement Concrete Pavements during Construction) is complete. The final report will be published in 2013.
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Measure the Structural Capacity of Pavement while Minimizing Traffic Disruptions

The structural capacity of pavement is a critical input for performing structural analysis of in-service pavements, identifying sections with structural capacity deficiencies at the network level, and designing pavement renewal or rehabilitation treatments at the project level. The use of continuous deflection measuring devices, which in some cases operate at traffic speed, allows for better spatial coverage with less impact on traffic.

This project assessed the demand and the potential value of continuous deflection devices for supporting pavement renewal decisions, and identified the technologies best

suited for effectively supporting the most critical decisions identified by potential users. This project demonstrated that at least one of the continuous deflection-measurement devices—the traffic speed deflectometer—can (a) provide adequate repeatability for network-level data collection; (b) collect deflection measurements and/or indices that are broadly comparable to those collected by traditional measurement devices; and (c) provide measurements that can be used for supporting some of the most critical network-level applications identified by potential users. However, the study also showed that the technology is only just maturing and identified possible improvements to make it even more useful and practical.

Products include a catalogue of existing continuous deflection measuring technologies, detailed assessment of the capabilities of the most promising devices, case studies illustrating the application of the technology for supporting various pavement management decision-making processes, a fact sheet describing the main technologies identified for continuously measuring pavement deflections and their potential uses, training materials for a workshop on the technology, research needs statements for the most pressing research identified, and a dissemination and implementation plan for the technology.

Status: SHRP 2 Project R06F (Development of Continuous Deflection Device) is complete. The final report will be published in 2013.
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Quickly Monitor the Condition and Deterioration of Tunnel Linings

Monitoring the condition and deterioration extent of tunnels is essential for determining the appropriate schedule of maintenance and/or rehabilitation activities to remedy structural and safety problems, which might lead to accelerated deterioration and sudden tunnel failures that could cause serious injury and even fatalities. Tunnels typically service high-volume traffic and operate in aggressive environments. NDT technologies have the potential to conduct (1) a rapid screening of the testing area and (2) an in-depth, although slower, assessment of an area deemed problematic during screening. In both cases, dependable NDT techniques can minimize disruption to traffic.

The objective of this project is to identify NDT technologies for evaluating the condition (including moisture, voids, and corrosion) of various types of tunnel linings (including unreinforced concrete, reinforced concrete, shotcrete, and steel) and finishes on tunnel linings (such as tile). The technologies must be capable of analyzing conditions within the tunnel lining and the surrounding substrate. The evaluation criteria include applicability, accuracy, precision, repeatability, ease of use, capacity to minimize disruption to vehicular traffic, and implementation and production costs. This project is also conducting development in hardware and software for techniques with demonstrated potential for technological improvement. The project is also conducting field evaluations to test the validity of the selected technologies/techniques to detect flaws within or verify conditions of the targeted tunnel components, and recommend test procedures and protocols to successfully implement these techniques.

Products will include a user's manual for NDT technologies that can detect defects behind or within tunnel linings. The manual will include information on equipment and systems integration requirements, test procedures, inspector's training requirements, data management procedures, data analysis procedures, limitations, and interpretation guidelines.

Status: SHRP 2 Project R06G (High-Speed Nondestructive Testing Methods for Mapping Voids, Debonding, Delaminations, Moisture, and Other Defects Behind or Within Tunnel Linings) is active. The final report will be published in 2014.
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A SHRP 2 Renewal Project Brief

Pavements for Rapid Renewal: Get In, Get Out, Stay Out

AUGUST 2012

Advanced pavement technologies offer highway agencies better options for pavement rehabilitation. These rapid construction methods not only can produce long-lasting pavements, they can significantly minimize traffic congestion and reduce risks to road users and road builders. These advanced technologies have been used successfully in recent years by a relatively small number of transportation agencies.

The second Strategic Highway Research Program (SHRP 2) has developed tools that make it easier for road owners to use advanced pavement technologies and gain the benefits of rapid renewal. The tools, briefly described here, include model design specifications for modular pavement technology, guidelines for constructing composite pavements, a new design that uses part of the existing pavement "structure" in place, preservation guidelines for high-traffic-volume roadways, and a web-based decision support tool for selecting geotechnical solutions to stabilize the base of roadways. Road builders can use these tools to get in, get out, and stay out.

Published reports for SHRP 2 projects are available at www.TRB.org/SHRP2/publications.

Modular Pavement Technology

Over the last 10 years, several transportation agencies—including California DOT, Illinois Tollway Authority, New Jersey DOT, New York State DOT, and Utah DOT—have implemented precast concrete pavement (PCP) systems; and Delaware, Missouri, Michigan, and Hawaii have constructed demonstration projects. The production use of PCP technology in the United States is, however, of recent origin, and information on modular pavement practices and performance is not well documented. Lacking this information, many highway agencies and industry partners have not fully embraced the technology.

To develop the necessary information and guidelines to encourage the rapid and successful adoption of this technology, SHRP 2 initiated project R05 (Modular Pavement Technology). Modular pavement technologies can deliver rapid repair and rehabilitation that also result in durable, longer-lasting pavements. This project conducted a review of the available modular pavement technologies, principally PCP systems, and summarized applications to date. The products of this research include model design specifications, and guidelines for the installation and inspection of PCP systems.

PCP systems are used in highway corridors with high-volume traffic and where lane closures are a challenge. For production use, the PCP work is performed at night with short closures, typically from about 9 PM to about 5 AM. The production rate per lane closure is about 15 to 20 repair locations and about 30 to 40 continuously placed panels (about 400 to 600 ft lengthwise).

Figure 1: SHRP 2 narrow-mouth slot system installed by Illinois Tollway Authority

Figure 2: Close-up of a finished exposed aggregate concrete texture that was constructed in Germany

The Illinois Tollway Authority worked on the initial pilot for one of the technologies developed in this project: narrow-mouth surface slot technology. Because of its success, the Tollway is already implementing the product in a 700-panel repair project. This will be one of the largest full-depth intermittent repair projects using PCP. The Tollway estimates savings of $500 per panel by using PCP and the narrow-mouth surface slot technology instead of conventional repair methods.

Availability: The final report for this project will be available late 2012.

Composite Pavements

Composite pavements have been proven in Europe and in the United States to have long service life with excellent surface characteristics, structural capacity, and rapid renewal when needed. Composite pavements also reflect the current direction of many highway agencies to build economical, sustainable pavement structures that use recycled materials and locally available materials.

However, while many transportation agencies may have performance data and models for conventional pavement systems, the behavior of new composite pavements is not well understood. Models for the performance of these hybrid systems are needed for design, performance prediction, and life-cycle cost analysis. Guidance on specifications, construction techniques, and quality management procedures are also needed.

In SHRP 2 Project R21 (Composite Pavement Systems), the design and construction of new composite pavement systems for all levels of highway and urban streets were investigated. This included determining the behavior, material properties, and performance for each type of composite pavement under many climate and traffic conditions. The project evaluated, improved, and further validated applicable structural, climatic, material, and performance prediction models, as well as design algorithms. To facilitate implementation, the project developed practical recommendations for construction specifications and techniques, life-cycle costing, and training materials. The recommendations focus on two types of composite pavement design strategies:

1. High-quality, relatively thin hot-mixed asphalt surfacing over a new portland cement concrete (PCC) structural layer; and
2. High-quality, relatively thin PCC surfacing over a thicker, structural PCC layer.

In May 2008, a survey of in-service composite pavement sites in the Netherlands, Germany, and Austria was conducted to assess the design, construction, and performance of composite pavement systems. The results of this survey were published as First Fruits Report S2-R21-RW-1 (*2008 Survey of European Composite Pavements*). The survey focused on the field performance of two types of composite pavements: asphalt over concrete; and two-lift, wet-on-wet concrete. It found that both types of composite pavements performed well under heavy traffic loading during the 10 to 20 years that they had been in service. Observations from this report were used to develop the field design, construction, testing, and evaluation plan for test pavement sections that were constructed in the United States.

Availability: The First Fruits report is available now as a web-only document. The final report will be published in 2013 as two volumes that will share a web-only appendix.

Achieving Long Life with In-Place Pavements

Renewal can be greatly accelerated and costs reduced when existing pavement can be incorporated into rapid renewal projects without having to be removed from the project site. To achieve long life under conditions of service likely not considered in the original design, however, requires the appropriate solution for specific circumstances. Project owners would benefit from comprehensive guidance and reliable procedures to identify when an existing pavement can successfully be used in place and how to incorporate it into the new pavement structure.

Project R23 (Using Existing Pavement in Place and Achieving Long Life) developed procedures that reliably identify when existing pavements can be used in place and the methods necessary to incorporate the original material into the new pavement structure while achieving long life (50 years or more). This project created decision matrices, design tables, and resource documents that provide valuable information regarding all aspects of a renewal project from project assessment, renewal selection, design, specifications, and construction.

This project provides guidelines for selecting, designing, and constructing long-life pavements using existing pavement structure. The guidance has been incorporated into a web-based pavement design scoping tool that is meant to complement a transportation agency's normal design and pavement type selection processes. The final report and the supporting documentation will encourage longer lasting designs; provide realistic, easy-to-use pavement thickness scoping assessments; and guide users through the data-gathering process needed to for input in designing and constructing a long-life pavement using the existing pavement structure.

Figure 3: Photo of 35-year-old unbonded PCC overlay on I-90 in Washington

Availability: The final report will be published in early 2013; the report will be available electronically and in hardcopy with a web-only appendix. The web-based tool will be available in early 2013 as well.

Preserving High-Traffic-Volume Roadways

For several years, pavement preservation has been an important strategy to extend the life of roadways. As transportation agencies grapple with decreased capital budgets, pavement preservation will continue to be an important strategy. Relatively small investments for preservation activities, if properly timed and applied, can significantly increase infrastructure life. Several transportation agencies apply preservation strategies on lower-volume roadways; however, the application of these strategies on high-volume roadways has lagged behind.

The application of preservation strategies to high-traffic-volume roadways presents a complicated set of challenges. Many of the products and approaches that are acceptable on lower-traffic-volume roadways are not acceptable or workable on high-traffic-volume roadways. Often, the use of a particular product or application has too great an impact on traffic, or the treatment is not successful under high-traffic conditions. To address these challenges, SHRP 2 developed guidance for more effectively matching the pavement condition and other considerations with suitable treatments for high-traffic-volume roadways.

SHRP 2 Report S2-R26-RR-1 (*Preservation Approaches for High-Traffic-Volume Roadways*) documents the state of the practice for preservation treatment on asphalt and concrete pavements. Although the focus of the project was on treatments suitable for application on high-volume roadways, this report also discusses current practices for low-volume roadways. The information presented is derived from a detailed survey of transportation agencies and a review of national and international literature. In addition, the report provides a general framework for how best practices are identified. Finally, general guidelines were developed on the application of preservation treatments on high-volume roadways. Presented as a separate document, SHRP 2 Report S2-R26-RR-2 (*Guidelines for the Preservation of High-Traffic-Volume Roadways*) considers traffic volume, pavement condition, work-zone requirements, environmental conditions, and expected performance.

Availability: Both reports are available as electronic copies on the SHRP 2 website and in hardcopy through the TRB bookstore.

Geotechnical Solutions

Pavements need a stable base. Because soils may be unstable, geoconstruction technologies are sometimes used to stabilize roadways. Many geoconstruction technologies, however, face both technical and nontechnical obstacles that prevent broader and effective application in transportation infrastructure projects.

SHRP 2 Project R02 (Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform) identified and assessed methods to advance the use of these geoconstruction technologies. Several of the identified technologies, although underused in current practice, offer significant potential benefits. Transportation agencies and other infrastructure industries, such as energy development, can use the products of this research to confidently select and use appropriate geotech solutions. The SHRP 2 products include design procedures and guidance; model specifications for geotechnical materials and systems; and Geotechnical Solutions for Transportation Infrastructure, a web-based information and guidance system.

Geotechnical Solutions for Transportation Infrastructure was developed to access critical information on geoconstruction technologies and to provide a tool that can help practitioners decide which technologies are applicable to site-specific conditions. The system is based on three project elements: (1) construction of new embankments and roadways over unstable soils, (2) widening and expansion of existing roadways and embankments, and (3) stabilization of the working platform. Geotechnical Solutions for Transportation Infrastructure includes 46 ground improvement and geoconstruction technologies and processes applicable to the three elements. It contains a technology catalog and a technology selection assistance tool, as well as sections on geotechnical design philosophy and a geotechnical glossary. The catalog includes eight end-user products for each of the geoconstruction technologies: Technology Fact Sheets, Photographs, Case Histories, Design Procedures, Quality Control/Quality Assurance Procedures, Cost Estimating Tools, Specification Guidance, and Bibliography. The primary value of this system is that it collects, synthesizes, integrates, and organizes a vast amount of important information about geotechnical solutions into a system that makes the information readily accessible to state transportation agency personnel.

Availability: The final report will be available in mid-2013. Geotechnical Solutions for Transportation Infrastructure will be available in late 2012.

SHRP 2 Contact

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A SHRP 2 Renewal Brief

Geotech Tools

Geoconstruction Information and Technology Selection Guidance for Geotechnical, Structural, and Pavement Engineers

NOVEMBER 2013

Geotechnical solutions are geoconstruction technologies or ground-improvement systems that alter poor soil and ground conditions to meet project requirements. Selecting an appropriate geoconstruction technology to use in transportation systems is a complex undertaking that depends on integration of available knowledge and a number of factors specific to both the problem and the site. Although geoconstruction technologies have existed for several decades, various obstacles prevent their widespread application in transportation infrastructure projects. To address the barriers and promote more widespread use of geoconstruction technologies, SHRP 2 Renewal Project R02: Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform investigated the state of practice and created the web-based tool Geotech Tools: Geo-Construction and Technology Selection Guidance for Geotechnical, Structural, and Pavement Engineers, which is available at www.geotechtools.org, to disseminate the research results. The project also produced two reports—*Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform* (the final report); and *Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform: Development Report* (which summarized the development of the website). This brief provides an overview of the Geotech Tools website, the development report, and the final report.

Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform (Final Report)

Transportation engineers, planners, and officials have expressed the need for a comprehensive system of access to critical information about geoconstruction technologies and for a tool to assist in deciding which technologies are potentially applicable to their projects. SHRP 2 Project R02 investigated current practices in transportation project engineering and geotechnical engineering to identify and assess methods to advance the use of these technologies. The final report describes the work, results, and products of this project.

SHRP 2 Project R02 examined a broad spectrum of materials, processes, and technologies within geotechnical engineering—ranging from structural foundations to grouting to vibro-concrete columns. In all cases, the project investigated the applicability of geoconstruction technologies to the following three project elements:

1. New embankment and roadway construction over unstable soils
2. Roadway and embankment widening
3. Stabilization of pavement working platforms

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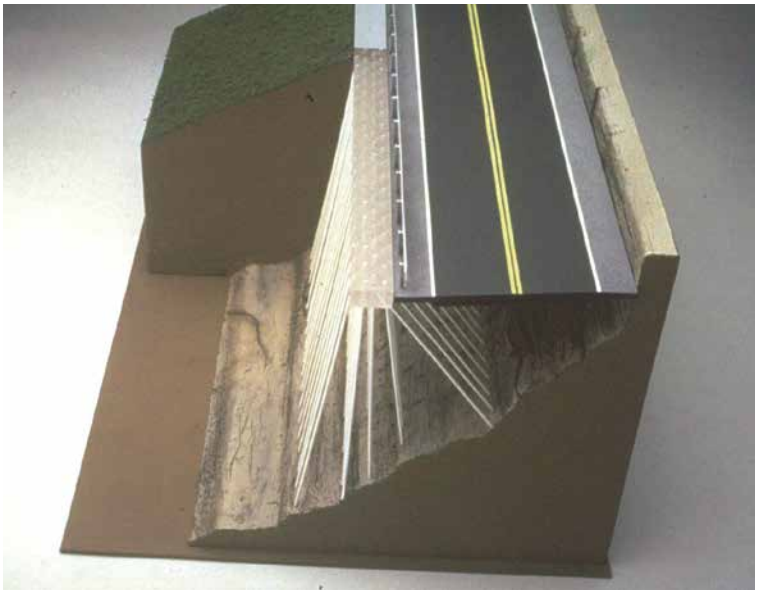

Micropile walls used for slope stability

To address the many technical and nontechnical impediments to widespread, effective use of geotechnical technologies in transportation, this project cataloged geotechnical technologies; developed design, construction, and quality control/quality assurance (QC/QA) guidance procedures; built cost-estimating tools; and crafted sample guide specifications.

Product Availability: Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform is available at http://www.trb.org/Main/Blurbs/168148.aspx.

Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform: Development Report

The development report describes how the Geotech Tools website was developed. It includes information about the project background and a literature review, as well as the development, programming, and testing of the website. This report also includes recommendations for future enhancements to Geotech Tools.

The website platform was developed using Adobe ColdFusion, and the programs were written in ColdFusion Markup Language. This particular programming language offered the versatility to complete dynamic websites that query databases. The JavaScript programming language provided interactive site content and allowed for live page updates based on user actions. The knowledge to complete both dynamically developed web pages and the interactive selection system was contained in a Microsoft Access database.

Geotech Tools was designed to use two approaches for technology selection. The first approach is that the system conservatively eliminates technologies during the process based on technical feasibility and project constraints. The second approach identifies a common theme throughout the selection procedure that helps users make the final selection of an appropriate technology. The tool leads the user to multiple technologies and provides the means for technology introduction, design, and cost estimating.

Geotech Tools is designed to assist, not replace, the technical specialist (geotechnical, structural and pavement). The engineer's experience and judgment should be the basis for the final selection process, taking into consideration the following factors: construction cost, maintenance cost, design and quality control issues, performance and safety (e.g., pavement smoothness, hazards caused by maintenance operations, and potential failures and poor performance), inconvenience (a tangible factor, especially for heavily traveled roadways or long detours), environmental aspects, and aesthetic aspects (appearance of completed work with respect to its surroundings).

Product Availability: Geotechnical Solutions for Soil Improvement, Rapid Embankment Construction, and Stabilization of the Pavement Working Platform: Development Report is available at http://www.trb.org/Main/Blurbs/168246.aspx.

Geotech Tools

The Geotech Tools website provides access to critical information on geoconstruction technologies. It can be used to help geotechnical, structural, and pavement engineers decide which technologies are potentially applicable to site-specific conditions. Geotech Tools includes 46 ground-improvement and geoconstruction technologies and processes applicable to the three project elements; a complete list is available in Table 1. It has a technology catalog and a technology selection assistance tool, as well as sections on design philosophy and a glossary. It also includes eight tools for each of the technologies in the catalog: technology fact sheets, photographs, case histories, design procedures, quality control/quality assurance procedures, cost estimating tools, specification guidance, and a bibliography. The primary value of this web-based information and guidance system is that it collects, synthesizes, integrates, and organizes a vast amount of important information about geo-

Table 1. Technologies in Geotech Tools Website

Aggregate Columns
Beneficial Reuse of Waste Materials
Biotreatment for Subgrade Stabilization
Blasting Densification
Bulk-Infill Grouting
Chemical Grouting/Injection Systems
Chemical Stabilization of Subgrades and Bases
Column-Supported Embankments
Combined Soil Stabilization with Vertical Columns (CSV)
Compaction Grouting
Continuous Flight Auger Piles
Deep Dynamic Compaction
Deep Mixing Methods
Drilled/Grouted and Hollow Bar Soil Nailing
Electro-Osmosis
Excavation and Replacement
Fiber Reinforcement in Pavement Systems
Geocell Confinement in Pavement Systems
Geosynthetic Reinforced Construction Platforms
Geosynthetic Reinforced Embankments
Geosynthetic Reinforcement in Pavement Systems
Geosynthetic Separation in Pavement Systems
Geosynthetics in Pavement Drainage
Geotextile-Encased Columns
High-Energy Impact Rollers
Hydraulic Fill + Vacuum Consolidation + Geocomposite Drains
Injected Lightweight Foam Fill
Intelligent Compaction / Roller Integrated Compaction Monitoring
Jet Grouting
Lightweight Fill, EPS Geofoam, Low-Density Cementitious Fill
Mechanical Stabilization of Subgrades and Bases
Mechanically Stabilized Earth Wall Systems (MSEW)
Micropiles
Onsite Use of Recycled Pavement Materials
Partial Encapsulation
Prefabricated Vertical Drains and Fill Preloading
Rapid Impact Compaction
Reinforced Soil Slopes
Sand Compaction Piles
Screw-in Soil Nailing
Shoot-in Soil Nailing
Shored Mechanically Stabilized Earth Wall System
Traditional Compaction
Vacuum Preloading with and without PVDs
Vibrocompaction
Vibro-Concrete Columns

technical solutions in a system that makes the information readily accessible to personnel at transportation agencies, contractors, and the consultant communities.

Geotech Tools was designed to achieve the following objectives:

1. Provide an information system that has a comprehensive technology catalog.
2. Provide technology selection assistance to help users develop a select list of applicable technologies based on key project and site characteristics.
3. Provide information and guidance for engineers to select a technology and develop a project-specific design based on project performance requirements and constraints.
4. Provide an interactive, fully functional, and populated knowledge resource to house the information system and guide users through the selection process.
5. Provide a glossary of the abbreviations and terms used throughout the information and guidance system.

Deep soil mixing

Roadway widening at abutment constrained by limited headroom and existing piles

The website, Geotech Tools, and the downloadable tools can be used by both technical and lay audiences to learn about the technologies. The website can be used to investigate potential solutions for general and for project-specific site conditions by browsing the technologies catalog, by using the technology category classifications, or by using the selection system. It can help users find procedures for design and QC/QA, and develop cost estimates and specifications. The interactive nature of the website allows users to test various project solutions efficiently. Lay users may find the technology fact sheets, photographs, and case histories valuable for quickly developing a basic understanding of a geoconstruction technology. The case histories provide examples where the technology has been used and they include transportation agency technical contacts, when available.

Product Availability: Geotech Tools is available at www.geotechtools.org. Those new to the website need to click on the "Not registered?" link to create a username and password before they can login.

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A SHRP 2 Renewal Project Brief

PROJECT R21

Composite Pavement Systems

MAY 2014

SHRP 2 Renewal research project R21: Composite Pavement Systems investigated the design and construction of new composite pavement systems that could provide longer-lasting facilities with lower life-cycle costs. While composite pavements have been in use for many years, in almost all cases they are not designed as composite pavements initially but become composite pavements through maintenance overlays. This project developed design and construction methods for new composite pavements. Two composite pavement design strategies were determined to provide both excellent surface characteristics (low noise; very smooth, nonpolishing aggregates; and durability) that can be rapidly renewed and long-lasting structural capacity for any level of truck traffic:

- High-quality, relatively thin, hot-mix asphalt (HMA) surfacing—such as dense HMA, stone matrix asphalt (SMA), porous HMA, asphalt rubber friction course (ARFC), or Novachip gap-graded asphalt rubber hot mix—over a new portland cement concrete (PCC) structural layer—such as jointed plain concrete (JPC), continuously reinforced concrete (CRC), jointed roller compacted concrete (RCC), or a lean concrete base/cement-treated base (LCB/CTB) and
- High-quality relatively thin PCC surfacing atop a thicker, structural PCC layer.

These types of composite pavements give significant flexibility to the designer to optimize the pavement design in terms of life-cycle costs, reduction in future lane closures, and improved sustainability. They essentially exhibit the advantages of conventional HMA and PCC pavements while reducing their disadvantages.

Constructed and Field Survey Sections

The investigation of the composite pavement systems pursued three specific objectives:

1. Determine the behavior, material properties, design factors, and performance parameters for each type of composite pavement.
2. Develop and validate mechanistic-empirical (M-E) based performance prediction models and design procedures that are consistent with the Mechanistic-Empirical Pavement Design Guide (MEPDG).
3. Develop recommendations for construction specifications, techniques, and quality management procedures for adoption by the transportation community.

To achieve the objectives, experimental composite pavements were constructed at two major research sites--MnROAD, Minnesota, and the University of California Pavement Research

Center [UCPRC] at Davis, California--and were instrumented and monitored under actual climate and heavy traffic loadings. In addition, the Illinois Tollway constructed an HMA/JPC composite pavement north of Chicago. Extensive field surveys were performed in the United States, Canada, and Europe of 64 sections of the two types of composite pavements and were used in the analysis and validation. Tables 1-3 provide examples of pavement performance reported in the surveys.

Composite Pavement Design

The design procedures in DARWin-ME for HMA overlay of jointed plain concrete pavement (JPCP) and continuously reinforced concrete pavement (CRCP) and in the MEPDG for bonded PCC overlay of JPCP and CRCP were found to be the most comprehensive and applicable for design of new composite pavements. Through use of appropriate inputs, the overlay procedure could be used for new com-

Table 1. Examples of HMA/PCC composite pavements in first performance period

(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE/TRUCKS	HMA LAYER	PCC LAYER	PERFORMANCE & MAINTENANCE	DESIGN, SUSTAINABILITY & LCCA
ARFC/JPC I-10, AZ; 17 years and 20 million trucks	1-in ARFC	14-in JPC 15-ft joints Dowels	Excellent performance; trans. joints refl. low severity; smooth; ARFC has lasted 20 years; no PCC cracks or repairs	DARWin-ME requires thinner slab design; low life-cycle cost over many years; no lane closures
SMA/JPC A93, Germany; 13 years and 47 million trucks	1.2-in SMA w/saw & seal joints	10.3-in JPC 16-ft joints Dowels	Good performance; trans. joints saw & seal; smooth; no PCC cracks; SMA spall repair	DARWin-ME gives same slab design; low life-cycle cost; few lane closures
HMA/CRC I-10, San Antonio, TX; 25 years and 24 million trucks	4-in HMA	12-in CRC HMA base	Excellent performance; no reflection cracks; smooth; no punchouts; no maintenance	DARWin-ME gives thinner slab design; low life-cycle cost over many years; no lane closures
HMA/RCC White Road. Columbus, OH; 7 years and 70,000 trucks	3-in HMA w/sealed cracks after cracking	8-in RCC 45-ft joints No dowels	Excellent performance; reflection cracks sealed just after cracked; smooth; no maintenance	DARWin-ME gives thinner slab design; short jt. space; low life-cycle cost; no lane closures
HMA/JPC I-94 MN; 1 year and 600,000 trucks	3-in HMA w/sawed & sealed joints	6-in JPC 15-ft joints Dowels	Excellent performance; sawed & sealed transverse joints good condition; no PCC cracks, smooth; no maintenance	DARWin-ME gives same design; PCC contains 50% RCA & 60% flyash

Table 2. Examples of "long-life" HMA/PCC composite pavements over several performance periods

(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE AND NO. OF TRUCKS	SURFACE AND REHABILITATION	BASE SLAB CHARACTERISTICS	PERFORMANCE AND MAINTENANCE	DESIGN, SUSTAINABILITY, AND LCCA
HMA/JPC I-5 Seattle, WA; 45 years and 35 million trucks	4-in. HMA original; 2-in. at 13 years; 2-in. at 16 years; 2-in. at 11 years; (some milling at times of resurfacing)	6-in. PCC No joints No dowels	Excellent performance; transverse cracks at 70 ft reflected medium severity after 8 years; smooth; replaced HMA at 11- to 16-year intervals; no additional transverse cracks; no PCC repairs	DARWin-ME would design thicker slab, add doweled transverse joints at 10 to 15 ft; saw and seal would extend life; low life-cycle cost over many years; few lane closures for rehabilitation
HMA/JPC I-294 Chicago, IL; 19 years and 30 million trucks	1992: 3.5-in. HMA original; 2001: Milled off and added 3-in. HMA; no additional rehabilitation after 10 more years	12.5-in. JPC 20-ft joint spacing Dowels	Excellent performance; transverse joints reflected medium severity; smooth; replace HMA at 9- to 10-year intervals; no transverse fatigue cracks in JPC; no PCC repairs	DARWin-ME gives thinner slab design; shorter joint spacing; saw and seal joints would extend life; low lifecycle cost over many years

posite pavement construction. Extensive testing and evaluations were performed, and many bugs related to composite pavements, as well as significant improvements, were identified and fixed in the MEPDG. A new version of the MEPDG (v. 1.3000:R21) was developed to use the Bonded-PCC-over-JPCP project to simulate newly constructed PCC/PCC and to address limitations of the existing structural and environmental models for PCC/PCC.

Table 3. Examples of PCC/PCC composite pavement characteristics, applications, and performance

(note: trucks given for heaviest lane, one direction only)

COMPOSITE PAVEMENT; AGE/TRUCKS	UPPER PCC LAYER	LOWER PCC LAYER	PERFORMANCE & MAINTENANCE	DESIGN, SUSTAINABILITY & LCCA
PCC/JPC I-75 Detroit, MI; 18 years and 72 million trucks	2.5-in EAC	7.5-in JPC 6-in LCB 15-ft jt. space Dowels	Fair performance; no transverse fatigue cracking; no joint faulting; smooth; only distress is joint spalling or debonding	Designed for very heavy traffic; low expected life-cycle cost; few lane closures
PCC/JPC FL-45, FL; 30 years and 5 million trucks	3-in PCC	9-in JPC Lower PCC Strength A, B, and C 15 & 20-ft joint spacing Doweled & Non-doweled	Excellent performance; low transverse fatigue cracking; low joint faulting	Pavement somewhat overdesigned; low life-cycle cost; no lane closures over 30-years; savings of cement; good sustainability
PCC/JPC A93, Germany; 13 years and 53 million trucks	2.8-in EAC	7.5-in JPC 16.4-ft jt. Space Dowels Tied PCC shoulders	Excellent performance; no transverse fatigue cracking; no joint faulting; smooth; low noise; pavement should last many more years	Designed for very heavy traffic; low life-cycle cost; no lane closures, good sustainability
PCC/JPC A1, Austria; 14 years and 47 million trucks	2-in EAC	7.9-in JPC (RCA materials) 18-ft jt. space Dowels ATB	Excellent performance; no transverse fatigue cracking; no joint faulting; smooth; low noise. Pavement should last many more years	Designed for very heavy traffic; low life-cycle cost; no lane closures; good sustainability
PCC/JPC K-96, Kansas; 14 years and 2.1 million trucks	3-in PCC	7 in JPC 15-ft Jt. Space Dowels PCC shoulders	Excellent performance (new pavement); no distress; smooth	Pavement over designed; low expected life-cycle cost; no lane closures
PCC/JPC N279, The Netherlands; 8 years and 11.9 million trucks	3.5-in EAC	7-in JPC 15-ft joint spacing Dowels	Excellent performance; no transverse fatigue cracks; smooth; low noise; no other distress	Well designed; low expected life-cycle cost; no lane closures
PCC/JPC I-70, Kansas; 4 years and 3 million trucks	1.5-in PCC 8 different surface textures	11.8 in PCC 15-ft Jt. Space Dowels PCC shoulders	Excellent performance (new pavement); no distress; smooth; low noise; Long life expected	Designed for very heavy traffic; low life-cycle cost expected
PCC/JPC I-94 MN; 1 year and 600,000 trucks	3-in EAC and diamond grinding	6-in JPC 15-ft joint spacing Dowels	Excellent performance; no transverse fatigue cracks; smooth; no maintenance	DARWin-ME gave this design for 15 year life, PCC 50% RCA, 60% fly ash, good sustainability

Recommendations for Composite Pavement Design

Based in part on these models and improvements made to the MEPDG/DARWin-ME software, the following can now be used in the design of new composite pavements:

- New HMA/JPC, HMA/RCC or LCB, and HMA/CRC can be designed using the overlay design feature in DARWin-ME.
- PCC/JPC and PCC/CRC can be designed using MEPDG (v. 1.3000:R21), which includes modifications to the allowable PCC layer thicknesses, representative PCC layer properties, slab and base interaction properties (full versus zero friction), PCC/PCC subgrade response modeling, and the distribution of the temperature nodes representing a thermal gradient through the composite pavement system.

Lattice Model for PCC/PCC Bonding

Extensive work was performed to more fully develop and use lattice models for composite slab simulations for debonding of the top PCC layer from the bottom PCC layer. Completed models coupled the lattice models with finite element models to provide a comprehensive model of the PCC/PCC interface bonding. For model simulations of realistic paving conditions in which newly constructed PCC/PCC pavements are placed in a reasonable time frame, debonding of the layers did not occur. Furthermore, additional simulations of layer behavior took into account unrealistic extreme thermal gradients and highly reduced shear strengths at the interface, and these simulations found failure at the interface in only the most extreme of cases, which would not be encountered in the field. This conclusion is supported by observations from the European PCC/PCC experience, as consultants to the R21 project were unable to cite an instance of PCC/PCC debonding. Based on these observations and model simulations, it was the assessment of the research team that debonding is only a concern in PCC overlays of existing PCC pavements, which was out of the scope of this project.

Research Products

The products from this research can be classified into five broad categories: (1) design, (2) construction and materials, (3) training, (4) informational, and (5) other. They are available online at http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Blurbs/168145.aspx.

Design Products

MEPDG (v. 1.3000:R21) developed under this study includes modifications to the allowable PCC layer thicknesses, representative PCC layer properties, slab and base interaction properties (full versus zero friction), PCC/PCC subgrade response modeling, and the distribution of temperature nodes through the composite pavement system. Many of these revisions specifically targeted the Enhanced Integrated Climatic Model (EICM) used by the MEPDG. This new program will be submitted to the American Association of State Highway and Transportation Officials (AASHTO) for consideration to incorporate the improvements into the DARWin-ME software. In addition, bug fixes and improvements related to both types of composite pavements were made to the MEPDG software throughout the R21 contract (e.g., crack opening error in HMA/CRC), and all of these modifications have been incorporated into the DARWin-ME software.

The structural fatigue damage and cracking models for both types of composite pavement were validated using all available data: MnROAD test sections, UCPRC test sections, and the existing 64 sections located in the United States, Canada, the Netherlands, Germany, and Austria. The existing global calibration factors were determined to be adequate. However, this does not mean that slab thickness will be the same for conventional or two-layer composite pavements.

- Various other structural and performance models for key distresses (rutting, joint faulting, smoothness) in new composite pavements were validated.
- Several detailed MEPDG design examples for composite pavements were prepared for guidance purposes. Comparisons of several examples with conventional JPCP or CRCP indicated a 1- to 3-in. reduction in required thickness for composite pavement. This reduction for HMA/JPC or HMA/CRC was attributable to a reduction in temperature gradients.
- Detailed recommended revisions were made to incorporate composite pavements into the MEPDG/DARWin-ME Manual of Practice.
- Guidelines and examples of life-cycle cost analysis were prepared. The life-cycle costs for composite pavement can be lower than those for conventional HMA or PCC pavements:

Construction and Materials Products

Construction specifications and guidelines were developed as part of construction at MnROAD and UCPRC for use by agencies considering constructing new HMA/PCC and PCC/PCC composite pavements. These include two-lift wet-on-wet construction of PCC/PCC pavements, timing and sequencing of operations, texturing procedures and related guidelines, guidelines for paving the stiffer lower lift PCC and the thin upper lift, saw cutting of joints, and the challenging exposed aggregate brushing technique. The MnROAD construction also involved the use of ultrasonic

tomography to assess PCC/PCC layer thicknesses and bond quality at the PCC/PCC and slab/base interfaces. The PCC upper layer was diamond ground using a next-generation grind that produces a smoother and quieter surface.

Material specifications include those for recycled aggregate, cementitious materials such as cement and fly ash, aggregate type and gradation for EAC, and retarding/curing compound. Procedural specifications include those related to wet-on-wet construction, such as timing of paving operations, texturing, saw cutting, sealing of sawed and sealed joints, tack coat application for HMA/PCC, and others.

Concrete freeze–thaw durability is a major concern for pavements in many parts of the United States and Canada. The International Union of Testing and Research Laboratories for Materials and Structures (Paris) (RILEM) CIF concrete freeze–thaw standard was adopted based on European PCC/PCC experience, and the equipment was imported from Germany for use in SHRP 2 R21. RILEM CIF freeze–thaw testing and evaluations were conducted on all the concrete mixtures used at MnROAD and they all adequately resisted surface scaling and internal damage (modulus) caused by frost action. Compared with the decrease in relative modulus of other concrete samples studied with the RILEM CIF procedure, the loss of scaled material and the decrease in relative moduli of all of the samples were relatively small. The lack of scaling and internal damage n both lower PCC mixes after 56 freeze–thaw cycles indicated that these mixtures are suitable for use in long-life concrete pavements despite containing recycled concrete aggregates or having a 60% cement replacement with fly ash, respectively.

Training Products

Materials were prepared to promote the use and accelerate the adoption of new composite pavements. The training materials include both design and construction materials. Design examples for both major types of composite pavements are included.

Informational Products

This project produced three reports: *Composite Pavement Systems: Volume 1: HMA/PCC Composite Pavements* (S2-R21-RR-2); *Composite Pavement Systems: Volume 2: PCC/PCC Composite Pavements* (Report S2-R21-RR-3); and *2008 Survey of European Composite Pavements* (S2-R21-RR-1). A fourth document, *Composite Pavement Systems: Appendices,* (S2-R21-RR-4) provides additional detail, history, and context. All four reports are available online at http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/CompositePavementSystems.aspx. A database of test sections, including material properties, performance, traffic, structure, and location, which are all inputs required for use with the MEPDG/DARWin-ME.

Other Products

Three test sections (two PCC/PCC and one HMA/PCC) were constructed at MnROAD with various surface textures (exposed aggregate, conventional grind, next generation grind, HMA) and design features (doweled/nondoweled and with/without sawed and sealed joints for HMA/PCC) with two different PCC mixes in the lower lift. These are the only instrumented in-service composite pavement test sections in existence. The instrumentation includes static and dynamic gauges, moisture gauges, and temperature gauges, all of which are wired into a data acquisition unit for continuously collecting data. These sections were constructed in April through June 2010 and were opened to traffic in July 2010.

Instrumented UCPRC HVS test sections were constructed in May 2010 and loaded with the HVS equipment. The instrumented test cells can be used for future testing. Data were collected from rutting and reflection cracking tests at UCPRC (including laboratory testing). HMA/JPC full-scale fatigue cracking tests using the HVS were conducted to validate the MEPDG transverse cracking models, and the results provided validation. Additional testing may continue with other funding.

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Renewal Project R26

Preservation Approaches for High-Traffic-Volume Roadways

MAY 2011

"As the results of the SHRP 2 research program are deployed, we will see more 'rapid renewal' tools developed for owners of the transportation system. The tools will lead to a fundamental change in how we approach rehabilitating our transportation system. We will be able to develop projects that are completed quickly, with minimal disruption to communities, and to produce facilities that are long-lasting."

— **RANDELL IWASAKI**
Executive Director, Contra Costa Transportation Authority and
Chair, Renewal Technical Coordinating Committee

This document highlights a new tool to help highway agency managers and engineers preserve high-volume roadways in serviceable condition for longer periods of time, at a lower cost, in a safer manner, and with limited disruption to the traveling public. It describes two products available in both print and electronic formats: Guidelines for the Preservation of High-Traffic-Volume Roadways *and a final report of the research conducted in Renewal Project R26:* Preservation Approaches for High-Traffic-Volume Roadways. *The research was also presented in a webinar, which is available through the SHRP 2 website. The Responsible Staff Officer for this project is Dr. James Bryant, Jr., who can be contacted at jbryant@nas.edu.*

As transportation agencies grapple with decreased capital budgets, pavement preservation will continue to be an important strategy to extend the life of roadways. Relatively small investments for preservation activities, if properly timed and applied, can increase infrastructure life significantly. Several transportation agencies apply preservation strategies on lower-volume roadways; however, application of these strategies on high-volume roadways has lagged behind.

The application of preservation strategies to high-traffic volume roadways presents a complicated set of challenges. Many of the products and approaches that have been accepted for use on lower-traffic-volume roadways have not made the transition to high-traffic-volume roadways. Often, the use of a particular product or application has too great an impact on traffic, or the treatment has not been successfully applied under high-traffic conditions. The purpose of the research project reported on here is to provide guidance for matching the pavement condition and other considerations more effectively with suitable treatments to preserve high-traffic-volume roadways.

Pavement preservation includes preventive maintenance and some forms of minor rehabilitation and corrective maintenance. The practice of pavement preservation is a growing trend

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among transportation agencies around the United States: In the early 1990s it was an obscure term, but it has since become standard practice at most highway agencies. The practice, however, is applied more to lower-volume roadways than to higher-volume roadways.

Practicing preservation on high-traffic-volume roadways is just as important as on low-volume roadways and for the same reasons: Pavement preservation

- Saves money;
- Provides the traveling public with safer, smoother roads; and
- Can be performed more rapidly than rehabilitation.

It is worthwhile to increase and improve the practice of pavement preservation on high-traffic-volume roadways.

Guidelines for the Preservation of High-Traffic-Volume-Roadways

Based in large part on agency experience and practice, the guidelines developed in this project provide direction on the selection and use of preservation treatments for high-traffic-volume roadways. The researchers expect that agencies will be able to extend their use of pavement preservation on high-traffic-volume roadways through a greater familiarity with the described treatments.

Key factors that affect selection of both pavement preservation projects and treatments include traffic level, existing pavement condition, climatic condition, available work hours, and treatment performance and cost. Traffic level is an important consideration because it is a direct measure of the loadings applied to a roadway and it affects access to a roadway to perform preservation activities. Because pavements typically have more than one distress type, the guidelines are structured to treat combinations of conditions. Climate conditions determine construction timing and affect treatment performance. Typical unit-cost ranges and corresponding relative costs of preservation treatments applied to hot mix asphalt- and portland cement concrete-surfaced roadways are shown in the guide. Figure 1 shows distress factors and treatment types.

Preservation Treatment Selection

Selecting an appropriate preservation treatment for a given pavement at a given time is not a simple process. It requires a significant amount of information about the existing pavement, as well as the needs and constraints of the treatment to be performed. In addition, usually several possible solutions can be considered, each with unique advantages and disadvantages. The process is further complicated when costs and cost-effectiveness are factored in.

The Guidelines present a sequential approach for evaluating possible preservation treatments and identifying the preferred one. The approach was developed specifically to address factors that are commonly considered for high-traffic-volume roadways. Figures, tables, and matrices are provided to help identify the best treatment for each situation. Figure 2 illustrates the pavement selection process described in the documents.

FIGURE 1 ***Causes of Distress and Treatment Types***

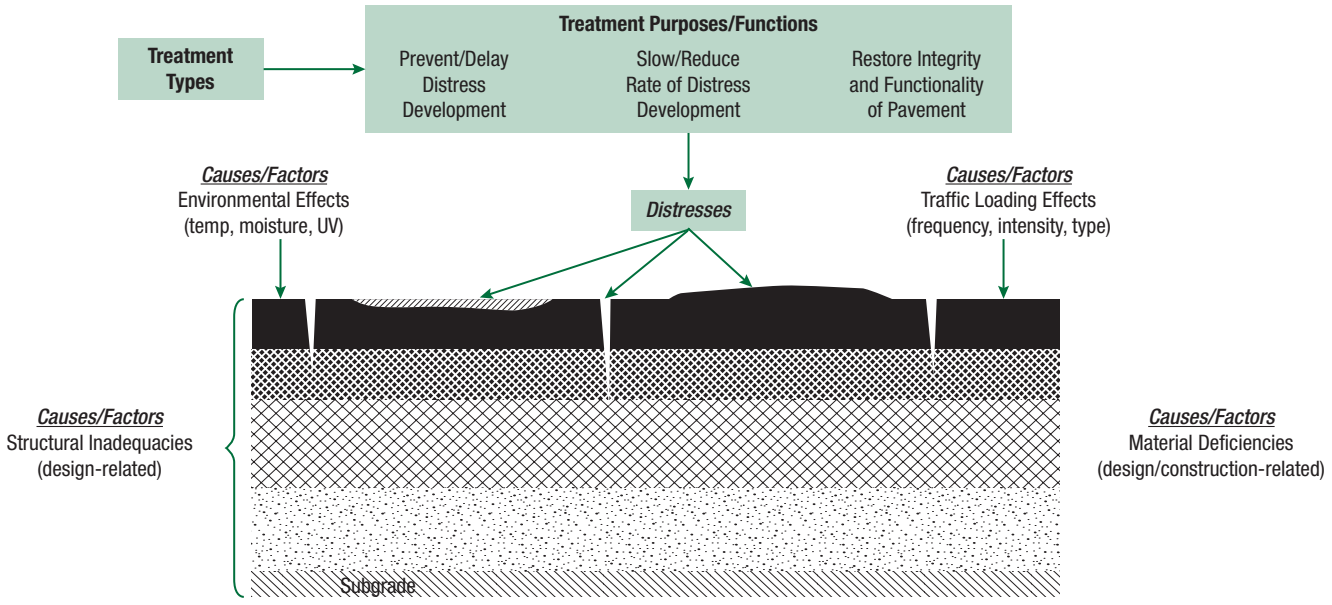
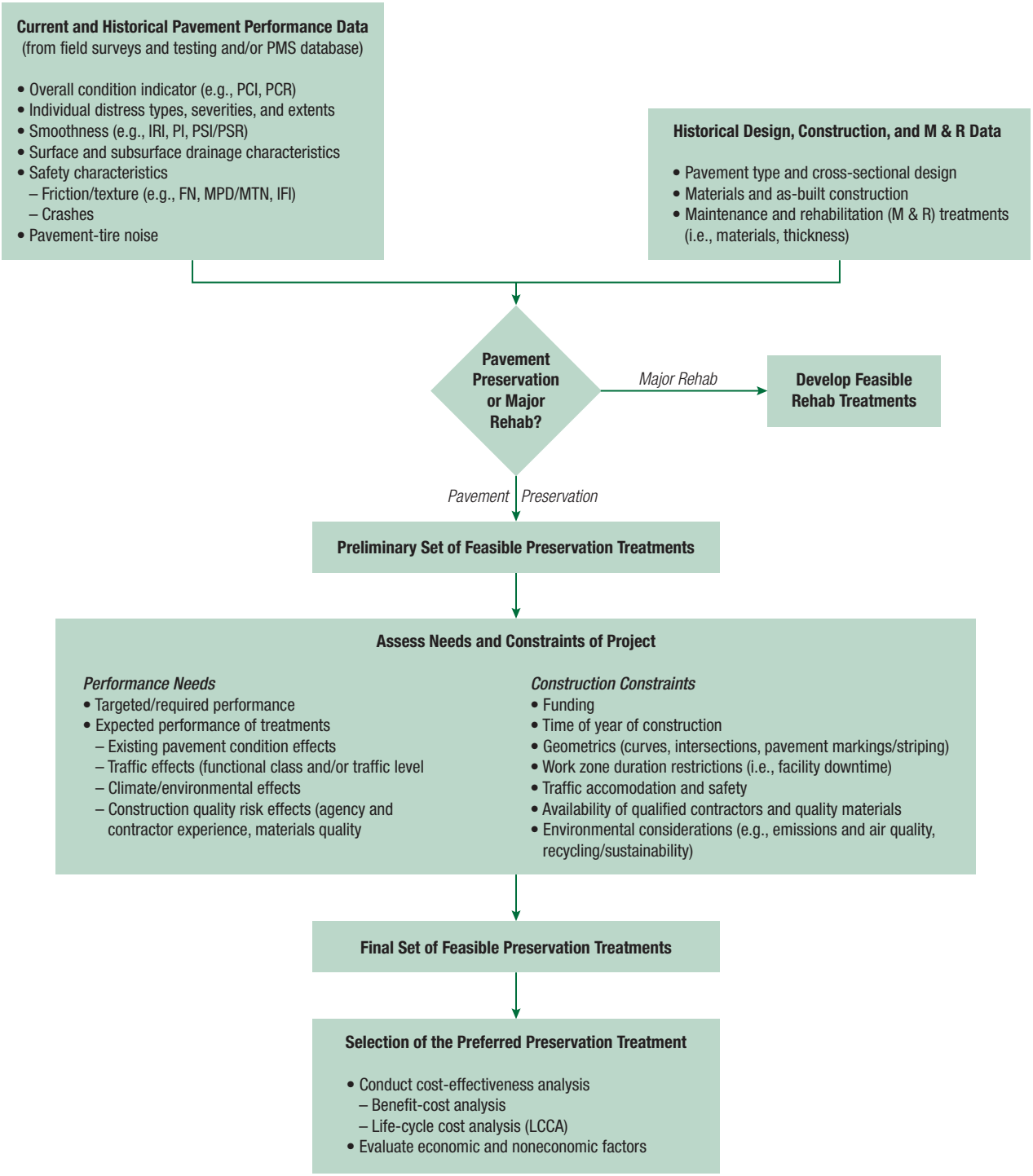


FIGURE 2 ***Preservation Treatment Selection Process for High-Traffic-Volume Roadways***



Appendix A to the Guidelines document provides technical summaries for each of the 14 preservation treatments covered in the document. The summaries include treatment descriptions, the key pavement conditions they address, and construction and other considerations, including expected performance, estimated costs, and references. Appendix B provides two example exercises that illustrate how to use the guide to identify feasible preservation treatments for a particular project.

The final report includes an annotated bibliography, the survey questions that were distributed to highway agencies and analyses of the survey responses, a discussion

of new and/or infrequently-used pavement preservation treatments, and a glossary. The survey found wide variation in the definition of high-traffic-volume roadways among responding transportation agencies. The definition used in the research project was rural roads with an average daily traffic volume of at least 5,000 vehicles per day and urban roads with at least 10,000.

The research team included D. Peshkin, K. L. Smith, A. Wolters, and J. Krstulovich of Applied Pavement Technology, Inc., Urbana, Illinois and J. Moulthrop and C. Alvarado of Fugro Consultants, Inc., Austin, Texas; and Gerry Eller, Dr. R. Gary Hicks, and Dean Testa. David Peshkin, Vice President of Applied Pavement Technology, was the Principal Investigator of this research project.

Guidelines for Preservation of High-Traffic-Volume Roadways can be ordered online through the TRB bookstore: http://books.trbbookstore.org/ or by calling 202-334-3213 8:30 am to 5:00 pm EST Monday–Friday. A PDF version is available on the SRHP 2 website at: www.TRB.org/SHRP2. The final report will be available later this year.

A SHRP 2 Renewal Project Brief

Meeting the Challenges of Rapid Renewal Projects

MARCH 2013

Rapid renewal techniques help transportation agencies speed delivery of highway renewal projects, but they also present a unique set of challenges. In an accelerated construction environment, workers and managers are more prone to fatigue. The short timeframes for these projects often require creative performance specifications to meet project objectives. And while risks are associated with all construction projects, they may be magnified under rapid renewal conditions. These projects are typically more complex than traditional construction projects, so they need different management strategies. Establishing an optimum sequence of projects along a corridor is also challenging, as infrastructure renewal projects need to maximize available resources, minimize disruptions to the traveling public and to adjacent land uses, and recognize political priorities.

When transportation agencies successfully navigate the challenges to project delivery, they can save time and money. This document describes tools agencies can use to mitigate worker and manager fatigue, develop and apply performance specifications, manage risk and complex projects, and sequence related projects.

Fatigue

Worker and manager fatigue can be a problem on highway construction sites, and it is only exacerbated by rapid renewal and accelerated construction practices, which may require longer shifts, night work, and weekend closures. This problem is widely acknowledged by both management and labor. Methods for dealing with fatigue tend to be informal, and there is wide variability in beliefs and attitudes about fatigue. Relevant fatigue countermeasures have been studied extensively and are already practiced in other industries. Countermeasures include strategic management interventions (such as fatigue training, work scheduling aids, and incident reporting), as well as individual interventions (such as sleep hygiene, napping, appropriate use of caffeine, and self- and peer-monitoring).

This project developed work scheduling and work practice guidance, organizational practice guidance, fatigue management reference material, training material for managers and workers, and outreach materials for raising awareness. This suite of products can help transportation agencies better integrate fatigue countermeasures into existing safety management systems for highway construction environments to reduce fatigue risk and increase safety.

Status: SHRP 2 Project R03: Identifying and Reducing Worker, Inspector, and Manager Fatigue in Rapid Renewal Environments is active. The final report and guide will be available in 2014.
SHRP 2 Contact: Jerry DiMaggio, jdimaggio@nas.edu

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

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Performance Specifications

Performance specifications can motivate and empower the contracting industry to create solutions that save time, minimize disruption, and enhance durability. By emphasizing desired outcomes and results, performance specifications challenge owners to think in terms of user needs and to recognize that more than one solution may achieve a project's objectives. Incorporating such concepts into a specification represents a distinct departure from build-to-print culture and requires a new approach to specification writing and contract administration.

This project developed model performance specifications that can be modified and applied to various topic areas (including pavements, geotechnology, work zones, and bridges) and project delivery methods (including design-bid-build, design-build, design-build-warranty, and design-build-operate-maintain). Implementation guidelines for the specifications were also developed to address issues related to project selection, specification development, procurement, and various other cultural and organizational changes.

Performance specifications have the potential to achieve the following objectives:

1. Reduce the completion time of renewal projects while maintaining or improving quality,
2. Encourage innovation by reducing mandatory means and method requirements and defining end product performance,
3. Address strategies to equitably manage and minimize risk to all parties.

Status: SHRP 2 Project R07: Performance Specifications for Rapid Renewal is active. The final report and guidelines will be available in 2014.
SHRP 2 Contact: James Bryant, jbryant@nas.edu

Risk Management

Risks associated with traditional transportation projects can be magnified in rapid renewal situations, in which accelerated environmental and permitting processes, design, and construction methods often are used in conjunction with innovative contracting methods. The consequences of unforeseen and unknown circumstances include project delays and budget over-runs, as well as disruption during construction and adverse effects on long-term performance. Although few state departments of transportation (DOTs) use formalized risk assessment and management programs on a routine basis, those that have adopted formal risk-based programs have realized substantial benefits.

This project developed guidance for managing risk during the development process for rapid renewal projects and for optimizing project performance with respect to cost, schedule, disruption, and longevity. The objectives were to (1) advance understanding of risk and risk management associated with the unique aspects of rapid renewal projects; and (2) develop practical guidance and materials so that state DOTs and others can apply risk management methods in ways that are consistent with their business practices.

To accomplish these objectives, the project developed a comprehensive guide (including checklists and an example project application) and implementation materials for conducting risk management on rapid renewal projects (including training materials, presentations, and forms for documenting the process). The guide presents a formal risk management process, which can result in an improved understanding of risks and optimized project performance by anticipating and planning for potential problems (risks) and potential improvements (opportunities). This process consists of a series of steps, including possible variations to prioritize and mitigate risks based on project specifics. Guidance is also provided for integrating a quality control component into the process to ensure compatibility and consistency among the steps, and to ultimately ensure adequate accuracy and defensibility of results. Use of these products can help DOTs, consultants, and contractors develop a culture of risk management and more successfully complete rapid renewal projects, as well as traditional renewal projects.

Status: SHRP 2 Project R09 is complete. The final report, Guide for the Process of Managing Risk on Rapid Renewal Contracts, guidelines, and training materials will be available in 2013.
SHRP 2 Contact: James Bryant, jbryant@nas.edu

Managing Complex Projects

Rapid renewal projects cover a wide spectrum of project types, varying in engineering complexity, size, modality, jurisdictional control, financing approach, contract type, and delivery method. Each project calls for a distinct project management style and for teams with different skill sets. Traditional project management has focused on cost, schedule, and quality, but now it is clear that complex projects incorporate the need to manage contextual factors and innovative financing techniques. Since the project management issues in these cases are markedly different from the issues with traditional projects, project management approaches also need to evolve.

To address this need, SHRP 2 developed a guide for applying a five-dimensional project management (5DPM) approach in Project Management Strategies for Complex Projects. The goal of 5DPM is to identify issues that should be planned for and managed proactively. The products of this research include a guidebook and a training program. The guidebook focuses on practical tools and techniques that were designed to be immediately beneficial to transportation professionals and should, when routinely applied, improve the state of practice in managing complex projects. The five dimensions of the new project management approach are outlined in Table 1, and an overview of the model can be seen in Figure 1.

Status: Research in SHRP 2 Project R10 is complete; pilot tests are ongoing through 2013. The final report is available at http://www.trb.org/Main/Blurbs/167481.aspx, and the guidebook is available at http://www.trb.org/Main/Blurbs/167482.aspx. The training materials will be available in spring 2013.
SHRP 2 Contact: Jerry DiMaggio, jdimaggio@nas.edu

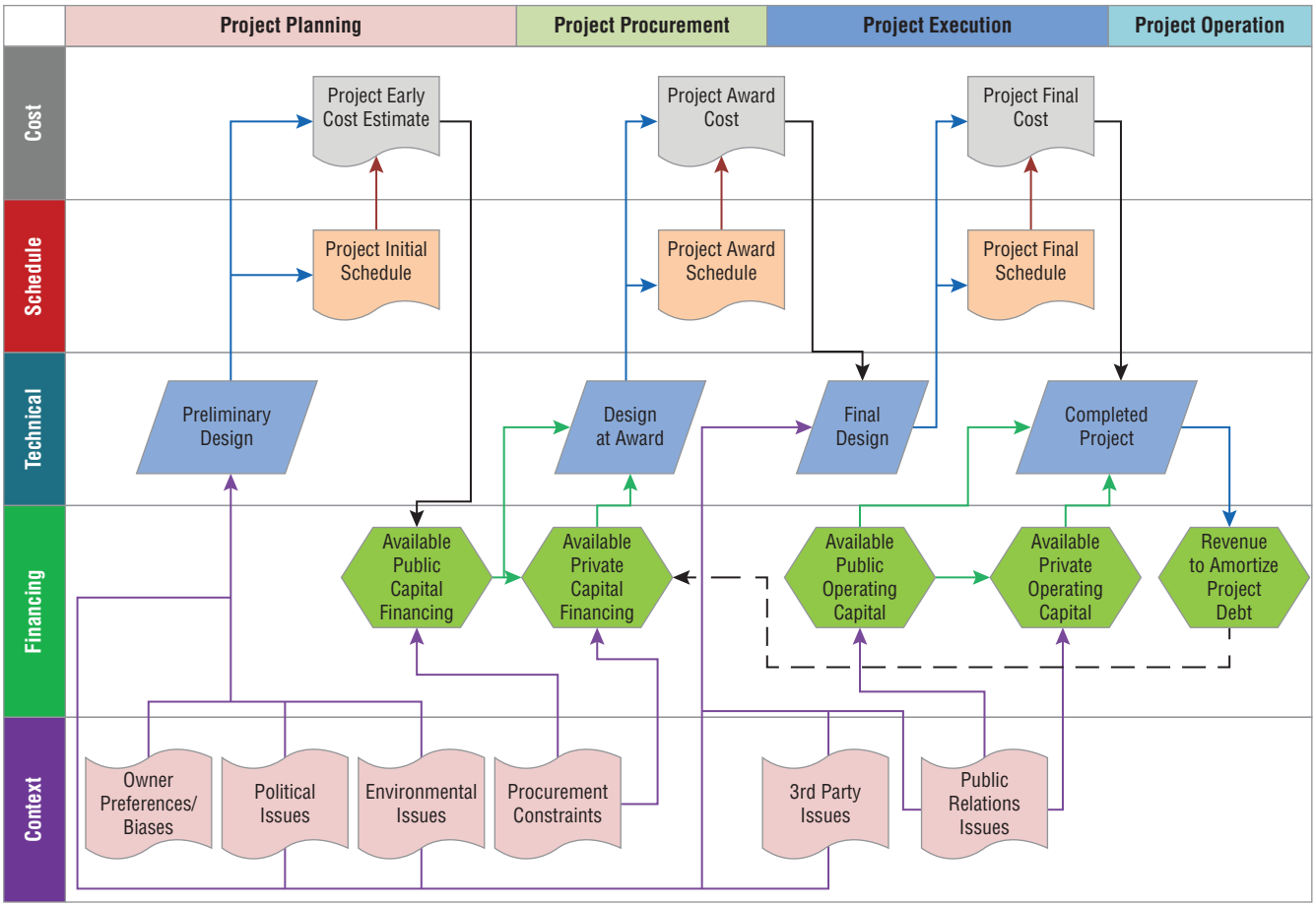
Table 1. The Five Dimensions of Complex Projects

DIMENSION	DESCRIPTION
Cost	Scope of work in dollar terms
Schedule	Calendar-driven aspects of the project
Technical	All typical engineering requirements
Context	External influences that have an impact on project development and progress
Financing	The need to understand how project funding impacts the final scope of work

Sequencing Programs of Renewal Projects

Program managers within DOTs and metropolitan planning organizations (MPOs) are charged with distilling a chaotic universe of identified infrastructure renewal needs into a logically sequenced program of manageable projects over a period of years. In addition, program managers must sequence programs of projects in ways that maximize available resources, minimize disruptions to the traveling public

Figure 1. 5-Dimensional Project Management Model



and to adjacent land uses, and recognize political priorities. Over the past several years, substantial progress has been made in the areas of performance measurement, maintenance of traffic, mitigation of congestion in work zones, and alternative contracting and construction techniques. This work was designed to minimize, manage, and mitigate disruption to traffic and commerce arising from infrastructure renewal programs. In application, however, performance measures are applied largely at the project level and impacts are not analyzed at the program level.

To assist program managers at DOTs and MPOs in sequencing programs of projects, this research developed a software tool known as WISE, which stands for Work Zone Impact and Strategy Estimator, and accompanying training materials. Using WISE, a program manager can assess the impacts of a renewal program and compare different sequencing scenarios of projects, in light of desired performance objectives. This tool is intended to create a more fully informed decision-making process regarding program sequencing and allocation of limited resources.

WISE can evaluate the regional impact of various infrastructure renewal strategies, such as day/night operations, innovative contracting, rapid construction techniques, advanced maintenance of traffic plans, and public information programs. Evaluations can be conducted at both the planning and the operational level. When used as a planning tool, WISE develops an optimized renewal programming schedule that minimizes delays to the public and agency cost. When used at the operational level, it evaluates the impact of individual strategies at the project level; the results can then be used as part of an iterative procedure with the planning analysis. WISE does not require the use of proprietary software; it builds on existing travel demand software used by DOTs and MPOs.

Status: SHRP 2 Project R11: Strategic Approaches at the Corridor and Network Level to Minimize Disruption from the Renewal Process is active. The final report is available at http://www.trb.org/Main/Blurbs/168143.aspx; WISE and the accompanying user guide are available at http://www.trb.org/Main/Blurbs/168144.aspx.
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A SHRP 2 Renewal Brief

PROJECT R09

Guide for Managing Risk on Rapid Renewal Projects

JANUARY 2014

Faster delivery of highway renewal projects yields benefits to both project owners and the traveling public. For example, faster delivery improves safety for the owner by reducing the time workers are in the roadway and reduces costs for the traveling public by reducing the period of restriction and disruptions.

"Rapid renewal" transportation design and construction projects are specifically intended to minimize both delivery schedule and disruption during construction, while not adversely affecting project cost and longevity. The innovative approaches and compressed schedules involved in rapid renewal often lead to different risk/reward allocations than those experienced in more traditional construction methods. A formal and structured risk management approach in which potential problems can be anticipated, evaluated, and addressed can significantly improve the chance of project success.

To support a systematic approach to the practice of risk management for rapid renewal projects SHRP 2 undertook a research project titled Guide for the Process of Managing Risk on Rapid Renewal Contracts (Project R09). The resulting Guide explains risk and how it can impact projects and defines a systematic approach to risk management. The Guide identifies six steps necessary to a formal risk management approach, provides case study examples for each step of the process, and includes extensive checklists and supplemental materials for conducting risk management on relatively simple rapid renewal projects. The supplements include annotated training materials, an animated presentation introducing the risk management process, forms for documenting the process, and a Microsoft Excel template (with User's Guide) that presents a hypothetical project using sample data to provide an example of how to document the process and automatically conduct the necessary analyses for successful rapid renewal risk management. The Guide and its supporting materials were successfully pilot tested in conjunction with a project in North Carolina and a risk assessment workshop in Washington state.

The Process

A formal risk management approach is intended to optimize project performance. The approach needs to be efficient and defensible, as well as adequate (as opposed to perfect), and it must be compatible with the DOT organization and its projects. The approach generally consists of the following two sequential and iterative actions:

1. "Diagnosis" – Identification of all the significant potential problems (and opportunities) that could affect project performance, and an adequate assessment of their current severity in terms of the potential impacts and likelihood of occurrence in each case. Such

"problems" (including opportunities) are relative to an assumed "base" scenario, which must first be defined, and are documented in a project-specific Risk Register. This might include an analysis of ultimate project performance, including quantification of uncertainty in that performance.

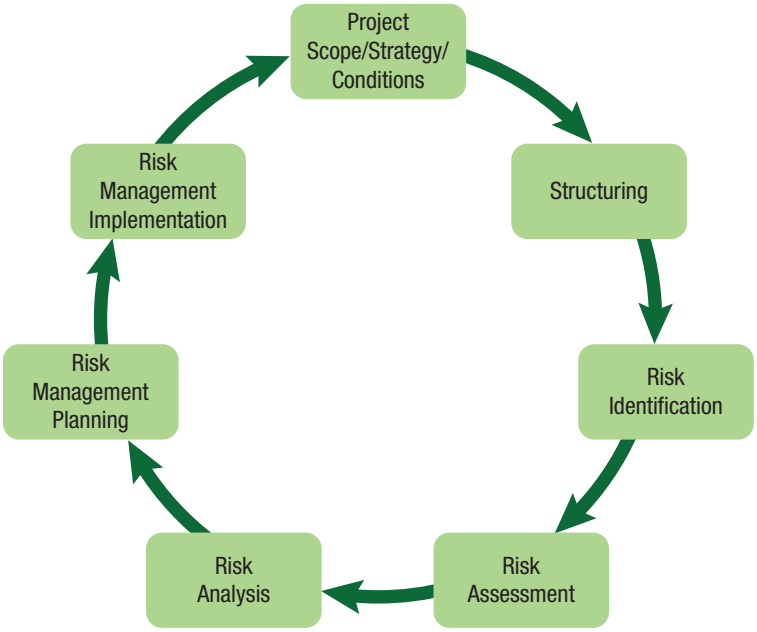
2. "Treatment" - Identification of feasible ways to manage the potential problems, evaluate the cost-effectiveness of the treatment and develop appropriate "contingencies." The treatment plans are documented in a project-specific Risk Management Plan. Implementation of the plan includes monitoring, updating (re-diagnosis), and decision making throughout project development and contract management.

The general process of successful risk management consists of a series of steps applied at various times throughout a project. The steps are shown in figure 1 and briefly described in the list that follows.

Iterative Risk Management Process

1. "Structuring" - Define the "base" project scenario against which risk and opportunity can subsequently be identified, assessed, and eventually managed. Project performance measures of cost, schedule and disruption, post-construction longevity, and the tradeoffs among these factors are included.

Figure 1. Iterative Risk Management Process



2. Risk Identification – Identify a comprehensive set of risks and opportunities. This is accomplished by brainstorming scenarios that might change the base project performance. Consult lists of common risks included in the guide. Document the set of risks and opportunities to start the project risk register.
3. Risk Assessment – Assess the "severity" of each of the risks and opportunities in the risk register, and then prioritize them on that basis. Generally this is done by subjectively assessing the risk factors (i.e., the probability of the scenario occurring and what are the impacts if it does), and then analytically combining the risk factors to determine changes in performance measures and thereby severity. Document the risk factor assessments in the project risk register.
4. Risk Analysis – Analytically combine the base and risk factors to determine the project performance measures (e.g., ultimate project escalated cost), as well as changes in measures associated with each risk. This can include quantification of the uncertainty in those performance measures, as a function of subjectively assessed uncertainties in the base and risk factors. Note that this step requires specialized skills.
5. Risk Management Planning – Identify and evaluate possible ways to proactively reduce risks, focusing on the most severe. Evaluate each possible action in terms of its cost-effectiveness, considering changes in both base factors (e.g., additional cost) and risk factors (e.g., reduced probability), and select those that are cost-effective. Consider subsequently re-analyzing the project performance measures for this risk reduction program, including quantification of uncertainty, based on which budgets and milestones can be established. As part of these budgets and milestones, contingencies (in the form of additional funds and time, as well as recovery plans) and procedures to control their use would be established. Document in the Risk Management Plan.
6. Risk Management Implementation – Implement the Risk Management Plan as the project proceeds by monitoring the status of risk reduction activities and changes in risk, and monitoring budget and milestones, especially with respect to contingencies. This might involve periodic updates at regular intervals or at major milestones or changes. For example, contingencies might be reduced as engineering reports or designs are completed and risks are avoided or reduced.

The Guide

The Guide outlines an efficient method for initiating the risk management process, preparing for and conducting the necessary meetings and workshops, documenting the process and results, and implementing the risk management plan. When following the Guide, users develop a Risk Register that helps identify and assess risks. The Risk Register documents the likelihood of each risk occurring during project phases and identifies a set of possible performance "impacts" if the risk occurs.

In the example below, the Risk Register entry is qualitatively assessing a risk related to rapid embankment construction. The probability of the risk occurring is medium and impacts to the three performance measures—cost, duration (completion date), and disruption (hours lost to the public)—are assessed. The components of the risk, the bulleted items in the table, could then be itemized to develop mitigation strategies that reduce risks to improve total performance and conduct further analysis to allocate/determine contingencies.

Rapid renewal methods include bridge slide techniques used on the Dingle Ridge Road Bridge project on I-84 in New York, which replaced the bridge in two weekend nights. (photo from HNTB)

The Training

A two-day course was developed to train DOT facilitators to conduct vital parts of the risk management process on relatively simple projects. This training is also useful for DOT management, key project team members, and independent experts, to help them better understand the process. However, this training is not required for everyone who participates in the risk management process. Course materials include forms and an MS Excel workbook template and an overview presentation.

A hypothetical (but realistic) DOT rapid renewal project is evaluated for illustration and concept reinforcement. While the Guide discusses what a risk management plan is and why it is useful, the training course focuses on how to implement a plan using simple exercises and examples. The emphasis is on structuring, risk identification, risk assessment (including risk severity analysis and prioritization),

Sample Risk Register

		FOR A MEAN-RATING RISK ASSESSMENT			
ITEM	RISK OR OPPORTUNITY	PROBABILITY OF OCCURRENCE (%)	COST CHANGE TO ACTIVITY (CURRENT $ MILLION	DURATION CHANGE TO ACTIVITY (MONTHS)	DISRUPTION CHANGE TO ACTIVITY (MILLION PERSON-HOURS LOST)
CN4	**Unable to constuct interchange embankments as rapidly as assumed** For the SH 111 overcrossing at the interchange with US 555. The performance of this planned rapid renewal method (rapid embankment construction) is difficult to predict for the following reasons (see *Guide,* Appendix D-2, or Table D-4c): • Uncertainty in subsurface conditions (soft soils are suspected); • Uncertainty in what method the contractor will choose • Uncertainty in performance of the selected method for actual subsurface conditions	M	+L to D/B Construction	+M to D/B Construction	+L to D/B Construction

risk analysis, risk management planning, and plan implementation, especially for relatively simple projects that a DOT can evaluate in-house, which will help to optimize the performance of those projects.

Benefits and Limitations

A formal risk management process can optimize project performance and increase agency understanding of how and when risks can become opportunities. The process reduces potential for cost overruns; is scalable to projects of any size; increases the likelihood of on-time delivery by anticipating and managing risks; reduces costs through better management of budget and schedules, and generally results in fewer surprises.

The risk management process can require significant effort and is analogous to a value engineering study in both its initial conduct and subsequent implementation. It must be planned, resourced, and facilitated to provide accurate analyses and defensible decisions as efficiently as possible.

The Risk Management Guide and its supporting materials are available at http://www.trb.org/Main/Blurbs/168369.aspx.

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James Bryant, Senior Program Officer, managed this project

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A SHRP 2 Renewal Brief

PROJECT R10

Strategies for Managing Complex Projects

MARCH 2014

Rapid renewal projects that replace, expand, or renew existing infrastructure vary both from new construction and from each other in several ways: engineering complexity, size, modality, jurisdictional control, financing approach, contract type, and delivery method. Each project calls for a distinct project management style and requires teams that comprise different skill sets to achieve successful completion. To meet the demands of rapid renewal, the practice of transportation project management is transitioning to an approach that recognizes this complexity and defines success by measures of project performance.

The objective of SHRP 2 Renewal research project R10: Project Management Strategies for Complex Projects, was to provide transportation agencies with innovative and effective project management strategies that can help accelerate sound decision making during rapid renewal projects. The research team investigated what makes projects complex and how complexity is being managed successfully. Fifteen projects in the Unites States and three international projects were investigated through in-depth case studies to identify tools that aid managers of complex projects in delivering projects successfully.

Through the case study analysis, the research team identified five dimensions of project management for complex projects, five methods for use on every complex project, and 13 tools that may be helpful on complex projects. These techniques underlie a new emphasis on the role and perspective of the project manager, which is discussed in detail in the project final report, Project Management Strategies for Complex Projects. A guide to implementing these tools was published in a separate volume titled, Guidebook: Project Management Strategies for Complex Projects; and training materials were developed to encourage adoption of the techniques. This project brief provides an overview of the new strategies and tools for managing complex projects developed by SHRP 2 Renewal Project R10.

Five Dimensions of Complexity

To meet the challenges of complex projects, both large and small, project managers ultimately must optimize the available resources (time and money) with the technical performance needs of the project (design), while operating under both known and unknown constraints (context) and accommodating the requirements of new financing partners and funding models (financing). These interrelated demands require owners to think continuously about risk and opportunity as they may arise in budgeting, scheduling, designing, allocating, and pricing. The five dimensions of complexity are further described in this section.

- Cost: Involves quantifying the scope of work in dollar terms. Cost considers project estimates, uncertainty, contingencies, project-related costs, and project cost drivers and constraints.

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- Schedule: Relates to the calendar-driven aspects of the project. The schedule considers time, schedule risks, prescribed milestones, and availability of resources.
- Technical: Includes all of the typical engineering requirements. This dimension considers design requirements, scope of the project, quality of construction, the organizational structure of the owner/agency, contract language and structure, and the implementation of new technologies.
- Context: Encompasses the external influences that have an impact on project development and progress. Context factors include stakeholders, environmental issues, legal and legislative requirements, local issues, and project-specific factors.
- Finance: Relates to the need for understanding how the project is being paid for and integrating that knowledge into the scope of work. The mechanics of financing can have a direct impact on the project design, the speed with which the project can be delivered, and the ability to achieve contextual requirements.

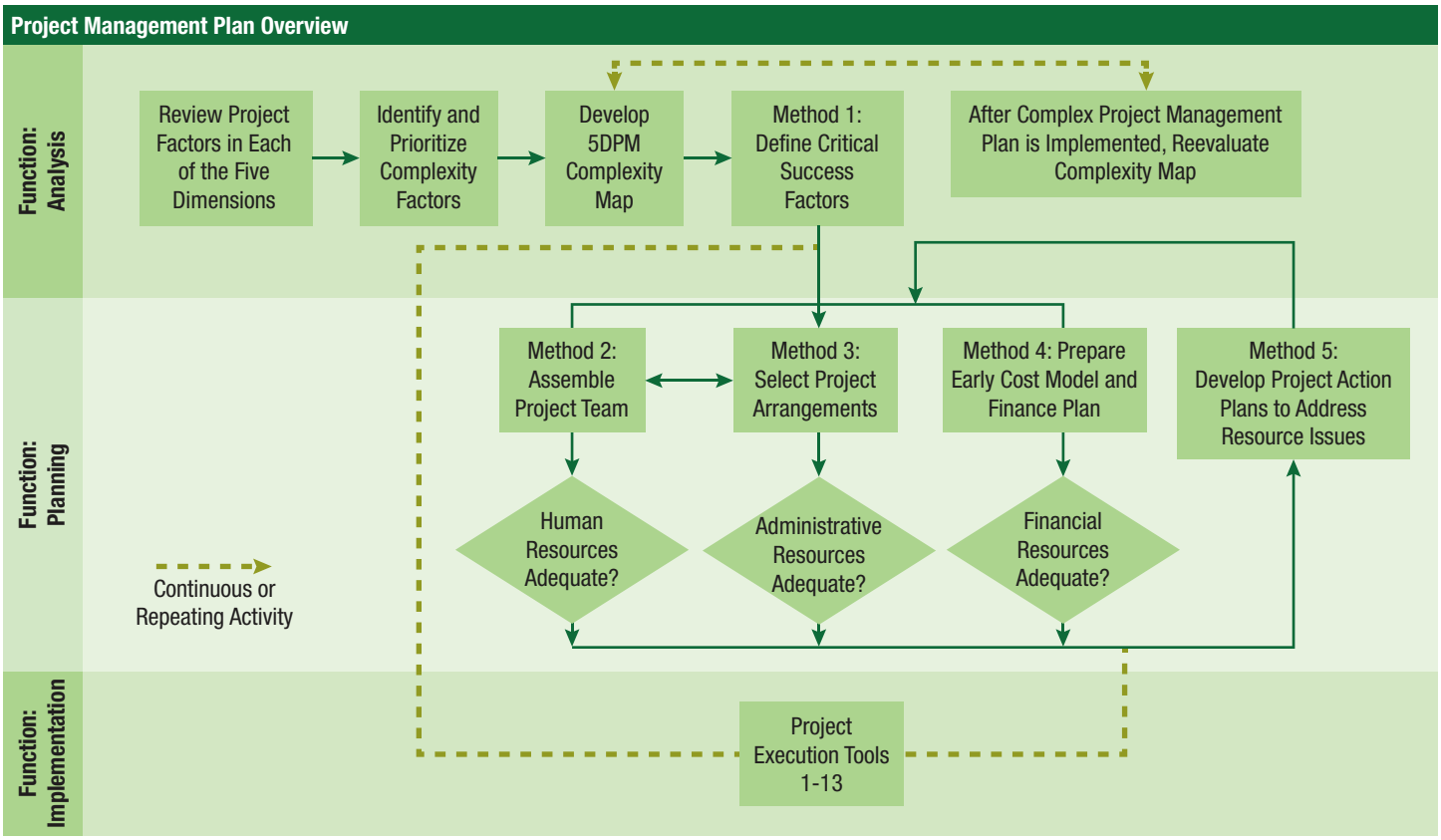
The basic premise of five-dimensional project management (5DPM) is that each dimension presents the manager of a complex project with a set of requirements to be satisfied and that optimizing the resources to ensure the project is delivered in the required period, with the available financing, and furnishing the requisite level of capacity, is the end goal of the process. Figure 1 illustrates the process flow for SDPM.

The SDPM approach starts by inventorying the project requirements and constraints and associating each with a given dimension. By identifying the constraints imposed on the project at a very early stage, the project manager can then gain input, support, and resources from the affected stakeholders so that the final project is satisfactory to all parties. Once completed, the inventory can be used as a risk register to generate the means and methods to deliver project requirements within the cost, schedule, technical, contextual, and financial constraints identified in the inventory.

Five Project Planning and Analysis Methods for Every Complex Project

The five project planning and analysis methods are used to identify project execution tools that can be used to help achieve the critical project success factors. These methods should involve executive-level personnel, as well as project-level personnel and should be implemented at the very earliest stages of the project lifecycle to effectively manage overarching degrees of complexity that are not attributable to one specific dimension of complexity.

Figure 1. Overview of complex project management and 5DPM process flow



In general, Method 1 involves identification of critical success factors, which are then used to allocate human (Method 2), administrative (Method 3), and financial (Method 4) resources. Any potential remaining barriers to success or resource constraints are addressed through targeted or general project action plans in Method 5. Tools such as a scale for scoring project complexity and complexity maps, as in Figure 2, help define and rank the critical project success factors.

Method 1—Define Project Success by Each Dimension: To overcome the uncertainty and irregularity that are characteristic of the dynamics of complex projects, the team needs a simplifying method to guide decisions and analyses. Complexity maps and flow charts are used to support the analysis.

Method 2—Assemble Project Team: The outcomes of Method 2 identify team responsibilities and authority. The process uses a gap analysis in which project needs such as skills, knowledge, responsibility, and authority are identified and compared to in-house resources and capabilities.

Method 3—Select Project Arrangements: The outcomes of Method 3 are the procurement plan, delivery methods, and other project arrangements (for example, interagency agreements, utilities, railroads, authority transfers, funding) that are required to achieve project success, as well as selection of project execution tools that support project success.

Method 4—Prepare Early Cost Model and Finance Plan: The outcomes of Method 4 are a cost model for the project, a list of secure identified funding sources, positive or negative differences in fund balance, and a funding plan, as well as selection of project execution tools that support project success.

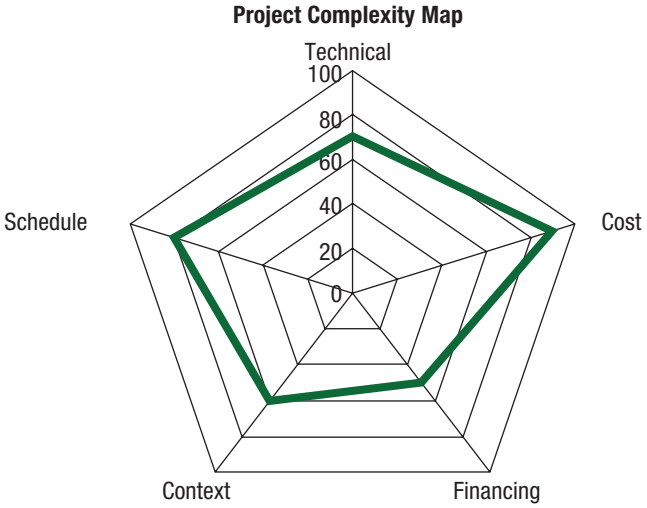
Method 5—Develop Project Action Plans: The outcomes of Method 5 are a clear understanding of the influence of external stakeholders and a plan to direct this influence positively to achieve project success, as well as targeted project action plans to overcome constraints and reduce delays. The goal of Method 5 is to develop innovative solutions, which can be administrative, contractual, technical, or methodological.

Execution Tools for Complex Projects

The research identified the following 13 tools that apply to one or several dimensions of complexity that will be realized during the project. Selecting which project execution tools to use should begin when defining the critical project success factors (Method 1) and continue throughout the process of using all five of the project development methods.

1. Attach Incentives to Critical Project Outcomes: The use of targeted incentives or disincentives can apply to financing, design, public relations, or construction contracts, as well as employment contracts and are highly recommended on complex projects. This tool should be used as early as possible in the planning process and should always be considered as part of the procurement plan. Development of performance metrics and incentive language may take place multiple times on a project, especially when partners join the team at different stages.
2. Develop Dispute Resolution Plan: The use of dispute resolution plans can help in managing complexity and potential setbacks in cost, schedule, technical/quality, context/stakeholder issues, and financing, and is highly recommended on complex projects. Dispute resolution methods should be established for each major project partner or stakeholder as soon as they are identified and invited (or contracted) to participate in the project.
3. Perform Comprehensive Risk Analysis: Comprehensive risk analysis can help manage direct risks from complexity in cost, schedule, scope/quality control, and indirect costs. Analysis of schedule and scope risks that arise from the potential impact of context/stakeholder issues and risks associated with project financing is highly recommended on complex projects.
4. Identify Critical Permit Issues: Identification of critical permit issues can control the cost, schedule, and scope impacts arising from context/stakeholder issues. Financing may be dependent on minimizing schedule and cost growth related to permit issues. Identification of critical permit issues is highly recommended on complex projects
5. Evaluate Applications of Off-Site Fabrication: Off-site fabrication must be considered, not only for

Figure 2. Example of resulting radar complexity map given scores for the five dimensions



schedule control purposes, but also quality control, minimal public disruption (such as noise and loss of access), and environmental impact control. Considering that complexity on projects may come from context issues, off-site fabrication can be a good solution for external issues in minimizing road closures, disruption to local business, traffic delays, detour lengths, and public inconvenience.

6. Determine Required Level of Involvement in Rights-of-Way/Utilities: Interaction with a right-of-way holder (such as a railroad) or a utility that cannot be avoided will result in schedule delays if not managed properly. Some flexibility in staffing, incentives, early coordination, etc., can minimize potential schedule impacts.
7. Determine Work Package/Sequence: Determination of work packages and sequences is recommended on complex projects when schedule and technical constraints make close coordination of work sequencing a requirement.
8. Design to Budget: Designing to a budget is recommended on complex projects when financing is constrained, cost control is possible without an impact on schedule, and there is flexibility in technical alternatives.
9. Co-Locate Team: Particularly on multi-jurisdictional (e.g., bi-state) projects, placing a dedicated, empowered , representative project team in a common location is important . Depending on the project delivery system used, the co-location strategy can be incorporated for design-build partners or the contracting team in later stages.
10. Establish Flexible Design Criteria: Use of flexible design criteria is recommended on complex projects when technical complexity and constraints in other dimensions makes use of standard designs and specifications impractical.
11. Evaluate Flexible Financing: Use of flexible financing is recommended on complex projects when few viable technical alternatives exist, contextual constraints are significant, and cost/schedule parameters require that the project move forward (e.g., the problems will only get worse if the project is put on hold).
12. Develop Finance Expenditure Model: Use of a finance expenditure model is recommended on complex projects when project technical scope is large and fixed, project cost is closely equal to available funding, and few alternatives exist that would not substantially delay the project.
13. Establish Public Involvement Plan: If context uncertainty or complexity creates a potential impact on cost and schedul e factors, a public involvement plan should be considered to manage external communication and public expectations. In addition, if innovative financing is used, a public involvement plan can be useful in educating the public as to the new methods employed on the project.

Products

The products of SHRP 2 Renewal Project Rl0 including the guide, workshops, and webinar materials complement established project management programs such as Every Day Counts, Accelerated Construction Technology Transfer, Highways for Life/Accelerated Bridge Construction, and the Major Project Delivery Process.

The guide uses examples from case studies of 18 complex projects to illustrate the concepts it describes. Training materials based on information in the guide can be used to help deliver 11/2-day workshops and to provide self-paced training in webinar format. The research report and the Guide Book are available at http ://www.trb.org/Main/Blurbs/167481.aspx . The training materials will be available on the same web page later in 2014.

RENEWAL STAFF

James Bryant, Senior Program Officer, managed this project

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A Renewal Project Brief

SHRP 2 Tools for Underground Utility Location, Data Collection, and Analysis

MARCH 2012

The Common Ground Alliance estimates that there are 35 million miles of underground utilities in the United States. That's about the same as the distance between Earth and Mars. Every day, utilities made of less-detectable materials are installed deeper underground. Much of the existing data on utility location, composition, ownership, and status (that is, whether active or abandoned) is missing, incorrect, or incomplete. Current technologies and tools can only find 80–90% of existing utilities. Finding the other 10–20% and successfully managing utility conflicts require new tools.

When a highway construction project is surprised by a utility, the results can include redesign costs, delay costs, change orders, claims, and damages (including repairs, environmental releases, and even human casualties). To reduce these negative impacts, several SHRP 2 projects are developing new tools to help locate and characterize underground utilities, as well as new tools to identify utility conflicts and solutions.

This document provides an overview of the SHRP 2 projects related to underground utilities. It includes a brief description and the status of each project. SHRP 2 hosted webinars on these projects in February 2012 and August 2011. Recordings of these webinars and PDFs of the slides are available on the webinar section of the SHRP 2 website: www.TRB.org/SHRP2/webinars.

Encouraging Innovation in Locating and Characterizing Underground Utilities

Throughout the years, underground utilities have proliferated within highway rights-of-way. The location and nature of many such utility lines have not always been properly documented. Moreover, the presence of underground utilities within the highway right-of-way and the lack of pedigree information about some utility lines present unique challenges for highway renewal activities, which often require relocation of underground utilities to ensure public safety. The untimely discovery of an unknown underground utility needing relocation is one of the major causes of delay during highway renewal projects and, as such, one of the major contributors to traffic disruptions and budget overruns. Decision makers in both transportation agencies and utility companies need timely access to accurate utility location information in order to minimize the risk of disruption during highway renewal activities.

In SHRP 2 Project R01, Encouraging Innovation in Locating and Characterizing Underground Utilities, researchers conducted a review of existing and emerging locating and mapping technologies, evaluated the existing locating needs, and developed a research and development plan to address those needs. The final report provides a thorough review of locating practices, current and emerging technologies, and recommended improvements.

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

TRANSPORTATION RESEARCH BOARD
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This project also developed the Selection Assistant for Utility Locating Technologies (SAULT), which is a web-based software tool that serves as decision support for identifying effective utility-locating methods for particular site and project environments. To deal with the complexity and multi-attribute nature of subsurface utility engineering and geophysical tools, the project team developed SAULT as an expert-based system. An expert-based system attempts to reproduce the performance of one or more human experts in a particular field. With SAULT, the user operates the expert system through an interactive dialogue that guides the user through a series of choices to solicit the needed input. At the end of the analysis, the user receives a summary report listing all the utility-locating methods deemed suitable for the project under consideration and any condition improvements that may facilitate the locating activities. Examples of technology in the software tool can be found in the box "Technologies in SAULT."

Status: This project is complete. SHRP 2 Report S2-R01-RW: *Encouraging Innovation in Locating and Characterizing Underground Utilities,* SHRP 2 Report S2-R01-RW-2: *Development of the Selection Assistant for Utility Locating Technologies*, and SAULT are available on the SHRP 2 website.

SHRP 2 Contact: Monica Starnes, mstarnes@nas.edu

Technologies to Support the Storage, Retrieval, and Utilization of 3-D Utility Location Data

Departments of transportation (DOTs) need accurate and up-to-date utility information during project development in order to consider the impact on utilities. Designers are usually provided with this information at the beginning of a project, but they do not have a mechanism to ensure it is kept up-to-date. There is currently no system in place to track utility changes during a project and notify designers of the changes, so DOTs need to completely remap utilities for every new project.

The research team in project R01-A is creating a system that provides a single, up-to-date repository for 3-D utility location data within a project boundary. It will leverage existing permitting and one-call processes to create a change notification system, develop supporting administrative procedures, and use existing DOT 2-D and 3-D CAD design software. The system could reduce redesign work resulting from utility changes unknown to the DOT designers, reduce project delays in the design and construction phases, and reduce excavation damage to utility lines. As part of this project, the research team will adopt and adapt a 3-D utility data model (proprietary model or industry standard), utilize a spatial document management system, leverage existing 3-D software tools, create administrative procedures, and incorporate supporting best practices.

The products of this research will include a 3-D utility data model, an implementation strategy, a proof-of-concept system, and a final report. The final report will include recommendations for further implementation, and technical and administrative best practices. DOTs, one-call centers, vendors, and service providers can use the process model and best practices to support further implementation.

The new tools can provide an automated means of understanding change within a project area and provide new 2-D and 3-D views of utility change without laborious research time. However, the tools will require additional training and understanding of the system nomenclature and work flow, and DOTs may have to adjust their work practices to use these tools. These tools can improve coordination, reduce risk of project redesign or delays, and reduce excavation damage. Over time, the tools could produce a current and comprehensive map of all utilities in a right-of-way, reducing or eliminating the need for new utility mapping at each project initiation.

Status: This project is active. A pilot project with Virginia DOT, Virginia Utility Protection Services, and participating utility companies will be conducted in mid 2012. The project will be complete in December 2012 and the final report will be available in 2013.

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Utility-Locating Technology with Multiple Sensors

Because utilities have differing materials, sizes, depths, conductivity, ground conditions, surface obstacles, and other characteristics, it is often necessary to use multiple sensing techniques to acquire an image of them. However, making multiple passes with different instruments is not as efficient as making one pass with a device that has multiple sensors. Combined with improved coupling techniques, a multi-sensor platform may lead to enhanced, perhaps automated, interpretation (better quality, lower risk) and better efficiency (less disruption and cost).

SHRP 2 Project R01-B, Utility-Locating Technology Development Utilizing Multi-Sensor Platforms, will support improvements in the detection and accurate determination of positions of buried utilities. The objective of this project is to develop digital geophysical mapping that can work in conjunction with common pipe and cable locating tools to offer more complete confirmation and verifica-

Technologies in SAULT

Array of Induction Receiver (AIR) System

This system is based on electromagnetic induction measurement techniques and operates on the same basic principles as traditional handheld radio-detection devices. An electric current is induced in a subsurface utility line. The induced current produces a magnetic field that is detected at the surface. The AIR system provides 48 simultaneous magnetic field measurements over an 8-ft. swath.

Radar MALA Easy Locator

The manufacturers claim that this device is capable of using high-frequency antenna for locating objects with diameters of 1 in. at a depth of 8 ft. and of locating objects with diameters 2 in. at a depth of 15 ft. using a mid-range frequency antenna. This GPR has a rough terrain cart for locating in rough areas.

Low-Frequency Conductive P/C Locator

The low-frequency conductive P/C locator has a built-in ohmmeter in the transmitter, which senses and measures the presence of external voltage while the receiver shows the received signal and its closeness to the cable. The lightweight earth contact frame directs the operator towards a fault.

Multichannel GPR: RFIL (Time-Step Frequency GPR)

The use of very short pulses (~1 nanosecond) and a repeated pattern of carefully timed and slightly offset signals support a high level of resolution (±50 mm), currently achievable only by high-frequency (1 GHz) GPR systems. Combining deep penetration and high resolution, the RFIL system can locate small targets such as inch-size plastic pipes at significant depths through challenging soils conditions.

Radio Mode: TW-8800

The TW-8800 uses three modes of active locating: conductive, inductive, and a coupling clamp. It also has two modes of passive locating: power (50 Hz/60 Hz) and radio (14 kHz and 30 kHz). The power mode can sense electrical lines and radio mode can sense redirected radio waves.

tion to *minimize*, not eliminate, the need for test holes. The more geophysical techniques used, the better the chance of performing a complete investigation beyond that of underground infrastructure that can include other targets of interest, such as pavement thickness, depth to bedrock or ground water, buried debris, and soil layers.

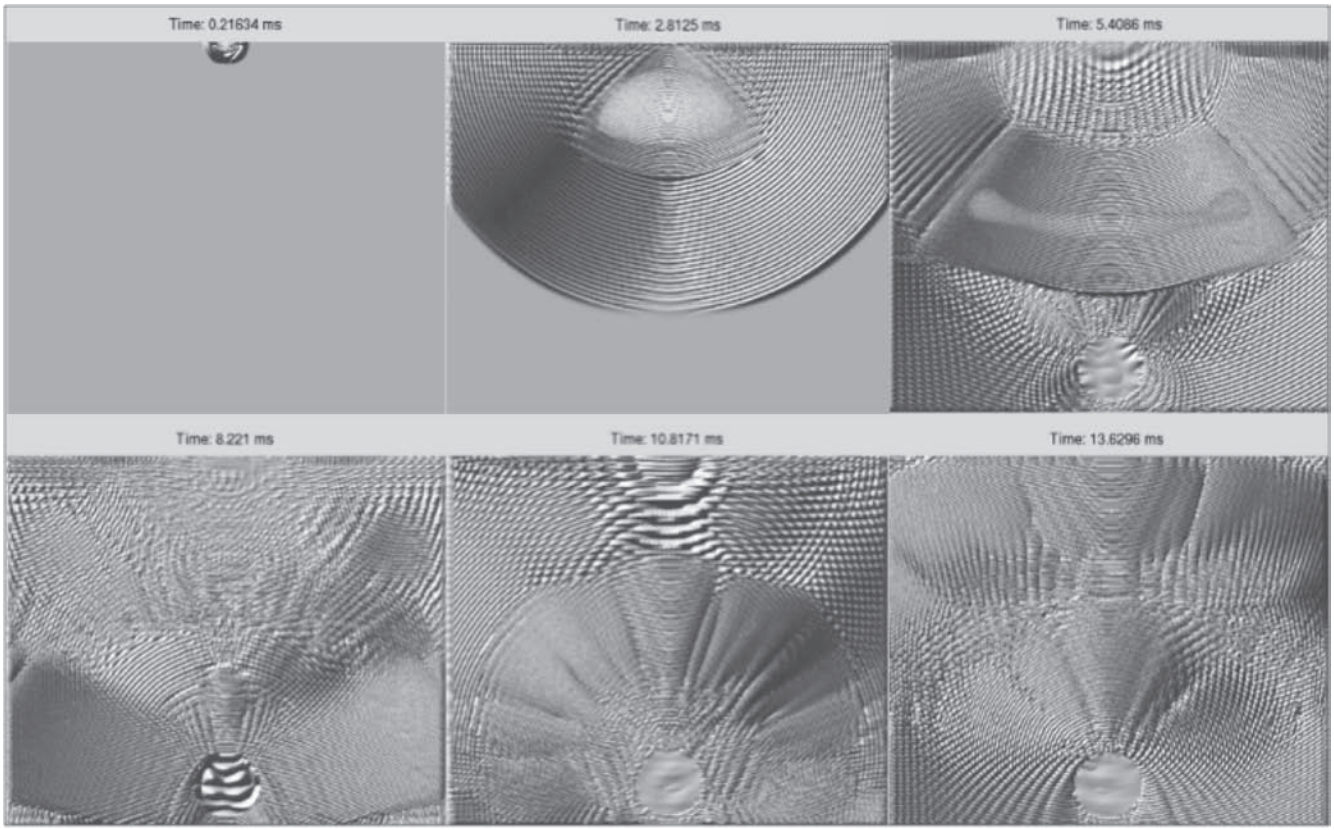
The systems being developed in this project include a high-frequency seismic imaging system, seismic modeling software, an improved time-domain electromagnetic induction (TDEMI) system, and improvements to data management software. The prototype seismic system will have a detection footprint and data format comparable to that of a multi-channel ground-penetrating radar unit, but use horizontal shear wave seismic reflection rather than radar reflection to image the subsurface. A portion of this project focuses on the development of modeling software to analyze the seismic measurements; in this task, real-world attenuation parameters, various sensor geometries, and target orientations are being introduced and simulated within the model. The TDEMI prototype system will be able to create a digital record (consisting of thousands of data points) of both detection samples and their associated precise position. The digital record can be used to conduct a detailed post-data-collection analysis performed by an experienced geophysical data processor in an office setting.

The software being developed will include the dynamic linking of maps, geophysical databases, and data profiles, as well as an automated depth slicing feature and arbitrary oriented cross-sectional view through a graphical/digital interface. These software advancements will facilitate a more streamlined and systematic workflow through the development of a more centralized analysis platform that will incorporate new improvements in data visualization, data management, and automated target selection routines.

These products are designed to advance the ability to rapidly and reliably locate and identify underground utility lines. Collecting data through multiple sensors reduces data acquisition time, lane closures, and training requirements. Having more reliable information reduces the likelihood of project delays from utility conflicts.

Status: This project is active. The report will be available online in mid 2013. Field testing of the TDEMI system will be conducted this year; it could be commercially available by 2013. A proof-of-concept seismic prototype can be built by 2013, and a refined production prototype could be available by 2015.

SHRP 2 Contact: Chuck Taylor, ctaylor@nas.edu



This image shows screen captures from left to right of a modeled seismic wave propagation path traveling from the ground surface (upper left) downward toward a cylindrical object (first seen in upper right) and then reflecting from the cylindrical object.

Innovations to Expand the Locatable Zone for Underground Utilities

Modern installation processes for installing underground utilities frequently require the utility company to go deeper. When utilities are installed deep, it can lead to "stacked" infrastructure. In addition, the materials that comprise modern utilities are more difficult to detect than traditional materials. To adapt, we need to improve both our means of locating deep infrastructure and our means of maintaining location data.

The objective of SHRP 2 Project R01-C, Innovations to Expand the Locatable Zone for Underground Utilities, is to improve the detection and accurate determination of the positions of buried utilities within an expanded locatable zone up to Quality Level B as defined by the American Society of Civil Engineers (ASCE) Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data (CI/ASCE 38-02), using any appropriate methods without duplicating the scope of project R01-B. This project is testing prototype technologies for locating buried facilities that are of diverse composition, at depths of up to 20 feet, obstructed or "stacked," and in the challenging road construction environment.

The tools being tested include a seismic reflection locator, an active/passive acoustic locator, long-range radio-frequency identification (RFID) tags, and a scanning electromagnetic (EM) locator. The seismic system targets all pipe materials, is staged completely above ground, uses shear waves to resolve smaller targets, and works in clay soils where ground-penetrating radar does not. Its current seismic techniques are suited for large and deep targets. The acoustic locator can target any pipe material and improves discrimination among facilities. The RFID tags have a range of up to 40 feet with a hand-held reader, a battery life of 20+ years, and IEEE 1902.1 public protocol communication. The EM locator uses low-frequency EM for depth of penetration; however, unresolved signal-strength issues are delaying testing and it may be dropped from the testing program. The technologies advanced in this project expand the 'locatable' zone of deep utilities with improved reliability. This location data eliminates delays when transportation projects involve underground utilities. The products of this project will include a user guide and training materials.

Visible Asset Inc.'s long-range RFID tag

Status: This project is active. The report, user guide, and training materials will be available online in early 2013.

SHRP 2 Contact: Chuck Taylor, ctaylor@nas.edu

Integrating the Priorities of Transportation Agencies and Utility Companies

Issues related to utilities are among the major causes of construction delays in highway construction projects. Because of the frequency with which utilities occupy existing highway rights-of-way, highway renewal projects are prone to setbacks related to relocation of existing utilities. Lack of accurate information on the location of underground or overhead utility assets, inadequate estimation of the time and budget needed to conduct utility relocation activities, and insufficient coordination and cooperation between transportation agencies and utility companies are among the key factors that contribute to construction delays. The demand for accelerated project delivery while minimizing the impact to the traveling public further highlights the need for adequate coordination and cooperation between highway agencies and utilities for many highway renewal projects.

Under SHRP 2 Project R15, Strategies for Integrating Utility and Transportation Agency Priorities in Highway Renewal Projects, a research team investigated how to improve coordination between utility companies and transportation agencies to reduce the negative impacts to both and to the public. The research was divided into two distinct, although not explicit, phases. The first phase of the project focused on data gathering to identify existing institutional issues and processes that contribute to delays in planning, designing, and constructing highway renewal projects, as well as identifying proven innovative practices, policies, and procedures to mitigate these delays. The second phase of the project focused on data analysis and development of recommendations. The team's findings and developed strategies for improving coordination between public agencies and utility companies were shared with an internal advisory panel in order to refine the recommended best practices and strategies. Based on the results, the research team developed a tool box of best practices and a set of recommendations for future research projects that could relieve the institutional barriers for effective utility relocation activities.

SHRP 2 Report S2-R15-RW: *Integrating the Priorities of Transportation Agencies and Utility Companies* documents

current practices, opportunities for improvement, and anticipated barriers for integrating utility and transportation agency priorities in highway renewal projects. Thirteen best practices that span the whole project life cycle are also documented in a tool box format. Finally, the report provides a plan for future research in this field.

Status: This project is complete. Report S2-R15-RW is available on the SHRP 2 website.

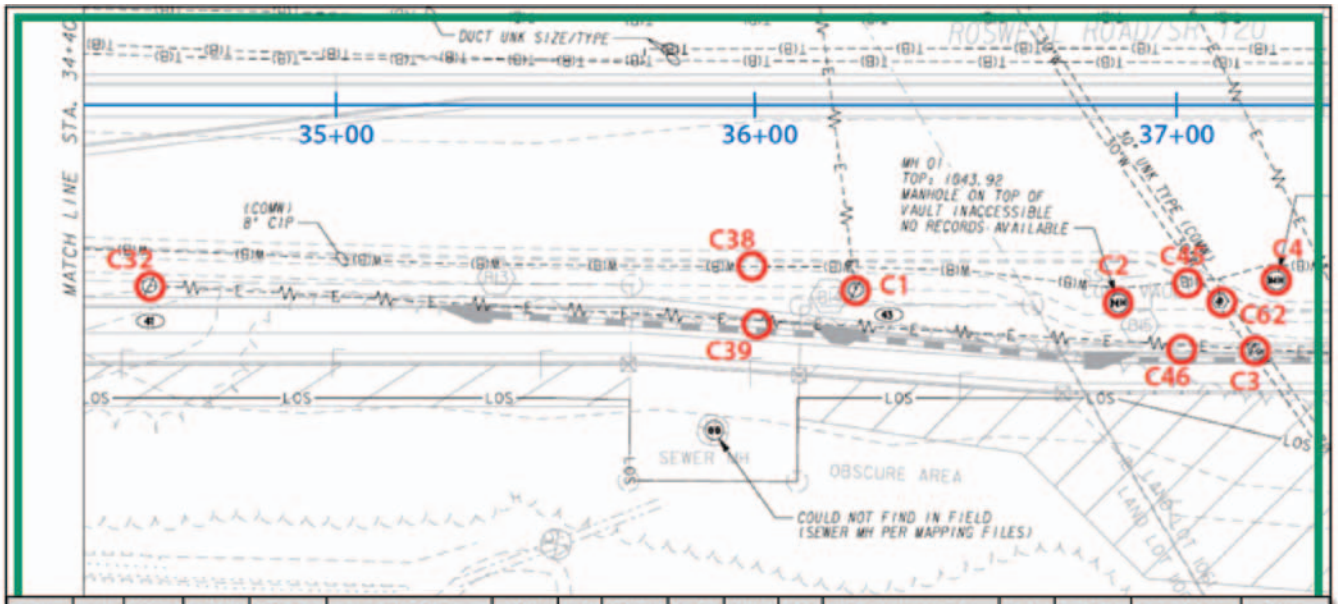
SHRP 2 Contact: Monica Starnes, mstarnes@nas.edu

Identification of Utility Conflicts and Solutions

Two critical factors that contribute to inefficiencies in the highway project development process are (a) the lack of accurate, complete information about utility facilities that might be in conflict with the project and (b) the resolution and overall management of those conflicts. When utility relocation is involved, construction generally takes longer and costs more. Identifying and resolving potential utility conflicts early in the design process can minimize these delays and costs. Utility conflict matrices enable users to organize, track, and manage these conflicts.

The report for SHRP 2 Renewal Project R15-B, Identification of Utility Conflicts and Solutions, provides comprehensive, optimized concepts and procedures for identifying and resolving utility conflicts that public agency and utility professionals can use to improve the highway project development process. The tools developed include utility conflict matrices (UCMs) that enable users to organize, track, and manage the conflicts that frequently arise when utility lines are under highways.

Procedures involving the use of UCMs vary widely across the country. This project began with the documentation of these procedures and then developed optimized UCM concepts and techniques. The major research activities were the review of current practice; the development and testing of an optimized UCM concept; the development of a one-day training course to instruct end users on how to use the optimized concept and tools; and pilot tests of the training for two state DOTs to fine-tune the course. In addition, implementation strategies and guidelines were developed that include specific steps to start and continue implementation. The optimized UCM techniques include a prototype standalone UCM in Microsoft Excel format that includes a main utility conflict table and a supporting worksheet to analyze utility conflict resolution strategies. Project



Utility Owner	ID	Sheet No.	Utility Type	Size/ Material	Utility Conflict Description	Start Sta.	End Sta.	Start Offset	End Offset	Inv. Need	Test Hole	Recommended Action	Rsp. Party	Est. Res. Date	Res. Status	Cost Analysis
	C3	1	WM	30"	Proposed 18" drainage pipe would cross WM.	37+20		60' Rt		QLA	3	Review possibility of adjusting drainage pipes up to avoid conflict, lowest structure (B13) is at 5.6'.	D	n/a	Utility conflict identified.	

Solution sheet from the UCM training course

products also include a prototype utility conflict data model and database. This standalone product is a scalable UCM that enables the management of conflicts in a database environment.

The one-day UCM training course developed in this project includes the following features:

- A lesson plan (six lessons—three in the morning and three in the afternoon);
- Presentation materials in PowerPoint format;
- Presenter notes;
- Participant handouts, including presentation handouts, sample project plans, and UCM templates; and
- A companion CD, which includes all the training materials and a copy of the prototype utility conflict database.

A critical component of the UCM training course is the hands-on utility conflict analysis in which participants analyze a set of plan sheets and other documentation to identify the location of utility conflicts and use a UCM to document and manage each conflict. At the end of the hands-on exercise, participants are given a copy of a solution sheet that shows the location of all utility conflicts and sample UCM records.

New efficiencies can result from having more standard procedures for documenting and managing utility conflicts. These products help optimize utility-related activities and simplify coordination between transportation agencies and utility companies, which will reduce a major cause of delay in highway construction projects.

Status: This project is complete. The final report, UCMs, and training course will be available in mid-2012.

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SHRP 2 Utility Projects

PROJECT NO.	PROJECT TITLE
R01	Encouraging Innovation in Locating and Characterizing Underground Utilities
R01-A	Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data
R01-B	Utility-Locating Technology Development Utilizing Multi-Sensor Platforms
R01-C	Innovations To Expand the Locatable Zone for Underground Utilities
R15	Strategies for Integrating Utility and Transportation Agency Priorities in Highway Renewal Projects
R15-B	Identification of Utility Conflicts and Solutions

SHRP 2 Renewal Reports Now Available

IN PRINT FROM TRB BOOKSTORE, AS E-BOOKS, AND ONLINE

Strategies for Improving the Project Agreement Process between Highway Agencies and Railroads (SHRP 2 Report S2-R16-RR-1)
E-Book for iPad, Kindle, Google Bookstore

IN PRINT FROM TRB BOOKSTORE AND ONLINE

Guidelines for the Preservation of High-Traffic-Volume Roadways (SHRP 2 Report S2-R26-RR-2)

Encouraging Innovation in Locating and Characterizing Underground Utilities (SHRP 2 Report S2-R01-RW)

Integrating the Priorities of Transportation Agencies and Utility Companies (SHRP 2 Report S2-R15-RW)

ONLINE ONLY

Preservation Approaches for High-Traffic-Volume Roadways (SHRP 2 Report S2-R26-RR-1)

Project Brief: Preservation Approaches for High-Traffic-Volume Roadways

A Plan for Developing High-Speed, Nondestructive Testing Procedures for Both Design Evaluation and Construction Inspection (SHRP 2 Report S2-R06-RW)

Project Brief: Tomorrow's Bridges

Project Brief: Railroad-DOT Institutional Mitigation Strategies

Project Brief: DOT-Utility Coordination: Understanding Key Aspects of the Problem and Opportunities for Improvement

www.TRB.org/SHRP2/Renewal

SHRP 2 ● TRANSPORTATION RESEARCH BOARD ● 500 5TH ST, NW ● WASHINGTON, DC 20001

SHRP2
STRATEGIC HIGHWAY RESEARCH PROGRAM

PROJECT BRIEF R01 MARCH 2009

Renewal Project R01: Encouraging Innovation in Locating and Characterizing Underground Utilities

This document summarizes the findings of SHRP 2 Renewal Project R01 and identifies three follow-on projects for which requests for proposals were advertised in March 2009. The final report from this project will include a plan of research for the development of innovative tools and methods for locating and identifying underground utilities. The project will also produce a web-based database of utility locating and characterizing equipment. The Responsible Staff Officer for this project is Monica A. Starnes, who can be contacted at: mstarnes@nas.edu.

Accurately locating and characterizing underground utilities to protect or relocate them is a major cause of delay in highway renewal projects, drawing out project development and delaying construction starts. In addition, damage to underground utilities can raise environmental, health, and safety concerns. For these reasons, improved technologies are needed to locate and characterize underground utilities.

SHRP 2 Renewal Project R01 examines ways to encourage innovation in the location and characterization of underground utilities. Phase I of the project identifies the areas of highest potential for innovation and improvement; Phase II develops a research and development plan to advance promising technologies.

Methodology

Areas of specific need and promising innovations were identified through the following methods:

- Questionnaire responses from state and local transportation agency personnel, transportation design engineers, and firms that locate and characterize utilities;
- Searches of the relevant literature and of patents and patent applications;
- A Statement of Needs technology search distributed to the Federal Laboratory Consortium;
- Input from national and international organizations; and
- Case history analysis.

Utility Issues in Transportation Projects

Many factors contribute to problems that can arise when underground utilities are present in transportation projects. For example, records of utility

presence, depth, and type are often incomplete, inconsistent, or inadequate for the needs of highway renewal projects. The fact that there may be multiple utility owners at any project location can cause further complications. Once utilities are located, additional problems may be encountered, including damage to the utility during construction. When project details are poorly planned, it may be necessary to move the utility more than once, or to disturb new pavement to accommodate the final correct utility installation. These problems are the basis for the widely recognized need for reliable utility location data and have given rise to the practice of subsurface utility engineering (SUE), which includes utility mapping, characterization, coordination, and design. SUE is most effective when systematically incorporated into organizational processes and introduced early in the design phase of transportation projects.

Utility Locating Technologies

Underground utilities can rarely be located visually; either remote means of location or excavation is required. Utility properties usually contrast those of the surrounding ground in terms of electrical conductivity, magnetism, heat, mass, electrical capacity, rigidity, etc. Geophysical location methods detect, image, and trace utilities by using these property contrasts. Many geophysical techniques for detection exist, but substantial improvements are required to achieve useful results. Two technical challenges associated with advancing the state of the art include, first, identifying new, more cost-effective techniques to locate and characterize utilities and manage the resulting data, and second, improving the detection abilities for difficult circumstances. The R01 project report addresses the range of both passive and active geophysical methods and summarizes the state of the art and of the practice for each method.

Improved methods of permanently marking utilities with visible markers, tracer wires or tape, buried magnets, or other detectable devices hold promise for better results. Though many of these methods are not new, technological advances have led to more sophisticated marking devices and these are detailed in the final report. One such emerging permanent marking method is radio-frequency identification (RFID) tags or balls. Details related to an underground utility are programmed into the RFID tag, which later can be quickly discovered using a surface scan. Although RFID has been used in the field for years, these methods are still in a developmental stage and show strong potential for locating and characterizing utilities as technology advances are implemented.

Excavation is a more reliable means of locating utilities than the geophysical methods, although it obviously poses a greater risk of utility damage. Two popular methods of loosening the soil—air/vacuum and water/vacuum excavation—limit this risk. The water/vacuum method is a less expensive option, but it poses a greater risk of damaging utility wrapping and coatings than air excavation methods and the excavated soil is not suitable for backfill. A backfill material that is increasing in popularity is control density fill (CDF). When mixed and applied correctly, it is easily fragmented and removed; yet when mixed improperly, it can become as hard as concrete.

Developing and maintaining accurate and complete records of existing utilities provides the best means for locating them for future transportation projects. Aside from few owners, such as interstate pipeline companies, there is no mandate for who should prepare utility records or develop standards for their accuracy or completeness. Exposing utilities for construction purposes provides an opportune time to update existing records, but this activity is rarely included in a project schedule or scope.

Developing and maintaining accurate and complete records of existing utilities provides the best means for locating them for future transportation projects.

Utility Characterization Technologies

The term 'utility characterization' refers to utility type, owner, size, material type, age, usage status, pressures, voltages, capacity, and condition. The report discusses various technologies for acquiring these basic characteristics through both external and internal inspection methods to identify metal loss, cracks, geometry, position, pressure carrying capacity, corrosion, bedding conditions, and pipe wall measurements.

Because only localized excavations are practical for external inspection, nondestructive tools are used to inspect buried pipes and these are detailed in the report. Internal inspection techniques have been a focus of development in recent years. Approaches to

internal inspection include a range of technologies to provide visual or acoustic information. Lasers and sonar methods, nonlinear harmonics, magnetic inductance, and X-ray inspection can detect internal pipe geometry. Dye, tracers, focused electrode leak, and other technologies can test pipe leakage and integrity. It is expected that combinations of inspection systems will become more common as sensor integration improves and costs decline for multiple measurements.

There have also been advances in managing the data that result from utility mapping, record-keeping, condition assessment, and life-cycle costs that have important implications for the interaction between utility companies and transportation project owners. Current data management tools allow for planning proactive maintenance, rehabilitation, and replacement and can lower life-cycle utility costs. There are, however, no industry-wide standards for collecting characterization data.

> Real risks are associated with not knowing if, where, and what types of utilities are located within highway right-of-way.

Possible Advancements

Improvements in detection capabilities, cost effectiveness, database integration, and real-time data retrieval are being advanced by a range of participants in both the transportation and utility communities. A sampling of promising technological developments includes an acoustic plastic pipe locator with a depth-to-diameter ratio capability of approximately 36:1 at a depth of 4 feet; plastic pipe that incorporates magnetized particles; merging a computer-assisted radar tomography array with an inductive array to produce digital mapping with a dual-array system; a multi-sensor time domain electromagnetic system that supports acquisition, processing, visualization, and interpretation of multiple sensor and supporting data in a 3D workspace; and underground sensing technologies developed for landmine and unexploded ordinance detection. These and other developing applications are described in the report.

Implications from Case Histories

The project final report includes case histories that highlight the benefits and results associated with locating and characterizing utilities. For instance, SUE mapping surveys are related to cost benefits in several studies: A 1999 Purdue University study reported that surveys performed when a project is 30% complete and using 0.125%–2% of the total construction costs, produce an average benefit-cost ratio of 4.6 to 1. A Virginia Department of Transportation (DOT) study found the ratio to be 7 to 1; a Society of American Value Engineers study documented a 10 to 1 positive ratio; and a Penn State University study for Pennsylvania DOT showed a 22 to 1 ratio. These ratios considered only savings in construction costs and schedule delays; costs associated with utility strikes and other qualitative measures were not considered.

Multi-channel Ground Penetrating Radar

Conclusion

Real risks are associated with not knowing if, where, and what types of utilities are located within highway right-of-way. Identifying and assigning costs to those risks will support rational decisions on appropriate tools and budgets for specific projects.

SHRP 2 Renewal research Project R01 identified and ranked potential solutions to the problems posed by underground utilities. Technologies that organize utility data and provide better methods of utility detection ranked higher than developments that would characterize utilities. Other highly ranked needs are guidelines that will maximize the benefit-cost ratio and further development of smart tagging technologies.

Three new research projects were drawn from the prioritized list of most-needed advancements and requests for proposals were released by SHRP 2 in

March 2009. These RFPs address the following topics:

R01-A: Innovation in Technologies to Support Storage, Retrieval, and Utilization of 3-D Utility Location Data in Highway Renewal

The goal of this project is to support the development of software and hardware to take advantage of recent advances in global positioning system and geographical information system technologies to increase the quality and efficiency of storing, retrieving, and utilizing utility records with three-dimensional positional information. It is also intended to demonstrate the collection and use of such information in a multi-utility environment. This would make it possible to reduce the time spent in repeatedly 'refinding' utilities so that resources can instead be focused on finding utilities that are unknown or incorrectly recorded. A comprehensive record of utility information beneath public right-of-ways would be a product of this practice.

R01-B: Utility Locating Technology Development Utilizing Multi-Sensor Platforms

The goal of this project is to support the technological development of multisensor approaches to improving the detection and accurate determination of position for buried utilities. Methods that leverage the presence of known utilities to improve detection performance are encouraged.

R01-C: Innovation to Expand the Locatable Zone for Underground Utilities

The primary objective of this project is to improve the detection and accurate determination of the positions of buried utilities within an expanded locatable zone up to Quality Level B as defined by the Construction Institute of the American Society of Civil Engineers' (CI/ASCE) standard 38-02, the Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data, using any appropriate methods without duplicating the scope of project R01-B. This objective may be accomplished by combining existing methods or developing new technologies. This project will also develop guidance that transportation agencies may use to include the developed innovative methods into their "Utility Accommodation Manual" and also can assist utility owners by expanding the locatable zone and improving detectability of future utility installations.

The research was conducted and a report was prepared by R. L. Sterling, J. Anspach, E. Allouche, J. Simicevic, C. D. F. Rogers, K. Weston, and K. Hayes. The lead institution is the Trenchless Technology Center, Louisiana Tech University. The cooperating organizations are So Deep Inc.; University of Birmingham, U.K.; and Civil Design & Construction Inc.

The Technical Coordinating Committee for Renewal Research in SHRP 2 oversaw the conduct of the research that is the basis for this report and reviewed its findings. The committee membership includes **Randell H. Iwasaki**, California Department of Transportation; **Daniel D'Angelo**, Office of Design, New York State Department of Transportation; **Thomas E. Baker,** Washington State Department of Transportation; **Thomas Callow,** City of Phoenix; **Steven D. DeWitt,** North Carolina Turnpike Authority; **Alan D. Fisher,** Cianbro Corporation; **Michael Hemmingsen,** Davison Transportation Service Center, Michigan Department of Transportation; **Dennis M. LaBelle,** M and T Consultants, Inc.; **William N. Nickas,** Corven Engineering, Inc.; **Mary Lou Ralls,** Ralls Newman, LLC; **John J. Robinson, Jr.,** Pennsylvania Department of Transportation; **Michael Ryan,** Michael Baker Jr., Inc.; **Cliff J. Schexnayder,** Chandler, Arizona; **Ronald A. Sines,** QC/QA Operations, P J Keating Company; **Doug Urbick,** A. Teichert & Son, Inc.; **Thomas R. Warne,** Tom Warne and Associates, LLC; **James T. McDonnell,** AASHTO; **Cheryl Richter,** Pavement R&D, Federal Highway Administration; **Steve Gaj,** FHWA; **Lance Vigfusson,** Manitoba Infrastructure and Transportation; **Frederick D. Hejl** and **Amir N. Hanna,** TRB Liaisons.

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SHRP2
STRATEGIC HIGHWAY RESEARCH PROGRAM

PROJECT BRIEF R15 MARCH 2009

Renewal Project R15: DOT-Utility Coordination: Understanding Key Aspects of the Problem and Opportunities for Improvement

This document summarizes the findings reported by the research team for Project R15 and offers strategies to resolve issues that Departments of Transportation (DOTs) and utility companies face when working together. The final report includes a plan to test and evaluate strategies designed to eliminate or mitigate utility asset relocation delays and overcome institutional barriers for the implementation of these strategies. The Responsible Staff Officer for this project is Monica A. Starnes who can be contacted at: mstarnes@nas.edu.

Utilities are frequently located on a highway right-of-way. This requires state DOTs and utility companies (UCs) to coordinate anytime renewal work on highways and bridges are planned. Current procedures for interaction between the organizations often thwart needed efficiencies. A 2001 survey of DOTs and transportation contractors ranked utility relocation as the number one cause of transportation construction delay.

In Project R15, a survey was conducted of all published information, to prepare for structured telephone interviews with DOT and UC relocation engineers and coordinators. The table on the following page displays the top three delay issues affecting design and construction.

The researchers identified four primary areas in which they focused their research:

1. Strategies to increase cooperation between UCs and DOT agencies;
2. Institutional barriers that impede implementation of strategies;
3. Evaluation methods for the strategies; and
4. Framework for effective project management in the project development process.

Creation of Strategies

The reasons for project delays were examined to identify their underlying causes. Strategies were then created to solve the delay problems by addressing the underlying causes. The strategies include:

Advanced Relocation of Utility Work

Conflicting utilities may be identified and located by UCs or contractors before the construction begins. Advanced notice by the DOT provides the UCs ample time to allocate funding for identification and possible reloca-

Primary Reasons for Project Delays Cited by UCs and DOTs

	UCs		DOTs	
Phase	**Frequency Ranking**	**Issue**	**Frequency Ranking**	**Issue**
Design	1	Limited financial and personnel resources	1	Short time frame for states to plan and design project
	2	Utility relocation not an integral part of design	2	Project design changes required changes to utility relocation
	3	Coordination with other utility agencies in the same proximity or government entities	3	Delays in obtaining rights of way for utility
Construction	1	Limited financial and personnel resources	1	Increased workload on utility relocation crews due to increase in highway and bridge construction
	2	Coordination with contractor to establish project plan to avoid relocating more than once for the same project	2	Utility lacked financial and personnel resources to execute relocation
	3	Coordination with other utility agencies in the same proximity and government entities	3	Inadequate coordination or sequencing among utilities using common poles and ducts

tion. Several state DOTs have reported success with this early action strategy. Yet, there can be numerous barriers. It is not always acceptable to create work zone delays twice: once for utilities and once for construction. In some instances, advanced utility work, can be very expensive. Also, legislative action may be required in some states to use advanced relocation.

Involve Utilities Early in the Planning and Design Phases

Involving the UCs early in the planning and design project phases has been proven to work well. Most DOTs notify UCs at the 30% design phase. This early contact can allow the designer to avoid some utility relocation and also allows the UCs to plan ahead, reducing construction delays. The existing barriers that impede routine implementation include: a lengthy right-of-way (ROW) acquisition process, UCs reluctance to proceed without assurance that the DOT will really build the project, and DOTs may wait to involve a utility company until the highway plans are finalized since plans often change.

Hold Preconstruction and Progress Meetings

Scheduling preconstruction and progress meetings throughout the construction phase can allow utility issues to be identified and solved quickly. The meetings improve communication between the UCs and contractors, but UCs indicate that they may not have the time to attend the meetings. The DOTs, UCs, and construction contractors would all benefit from working as a team to schedule meetings that all parties can attend and ensuring that meetings are effective and productive

Provide Incentive for Early Relocation

Some DOTs will reimburse a UC for the relocation of a utility. In Tennessee, for example, utility reimbursement occurs at the discretion of the DOT commissioner. However, new legislation would be required for this to occur in most states because additional funding is required to implement the practice. Nevertheless, even with the incentive, some UCs may not be able to perform the work before construction begins.

Include Utility Relocation Work in the DOT Construction Contract

If the utility relocation work were included in the contractor's work, many of the scheduling problems between the UC and the DOT contractor would be avoided. This approach can allow the DOT contrac-

tor to be more efficient, but assumes the UC is willing to allow the contractor to perform the work. In some cases the construction contractor might not have experience working with the type of utility involved in the relocation. For this strategy to be plausible, the construction contractor would need to be trained to address the issues related to that specific utility. This strategy may also require state legislation, since the DOT would have increased liability in this construction scenario.

The above strategies and others were ranked, using input from DOTs and utility industries. In the implementation of any of the strategies, DOTs can document and assess whether or not the practice reduced design and construction schedules and saved time. The assessment can also analyze if the practices improve communication between the DOTs, UCs, and construction contractors. Even with the implementation of new strategies, many DOTs emphasize that it will not be easy to mitigate all of the existing problems. In particular, scheduling conflicts and competing priorities are a constant challenge to some of the suggested best practices. All of the parties involved need to be committed, follow the process, and perform each task. UCs and DOTs state that "If any of the parties involved fails to do its part, the process can falter or fail."

UCs and DOTs state that "If any of the parties involved fails to do its part, the process can falter or fail."

Recommended Future Research for SHRP 2 Renewal

Based on the evaluation of the suggested strategies, the project team developed and recommended research project statements for SHRP 2. The following are synopses of the research project statements.

Information Management Systems to Support Utility Relocation and ROW Management

DOT ROW managers and designers have to work with a large volume of complex utility location data, the majority of which is not in a digital format. Using the best available information management technology could help manage the data. This project would investigate the feasibility of putting this technology into use, develop the criteria for functionality, and create a plan for product development.

Model Curriculum in Utility Relocation Engineering for Transportation Designers

DOT designers and construction engineers have little or no formal training in the technical aspects of complex utility systems. This project would create a model training curriculum to satisfy core competencies that a DOT design specialist requires to effectively address utility relocation issues in the transportation design process.

Onsite Utility Construction Coordination

One Call statutes require that utilities be marked on the ground before construction begins, but in routine practice not all utilities are marked and the markings do not always match the locations shown in the plans. It is usually the responsibility of the construction contractor to address these discrepancies. A model that could be more effective would be to assign an onsite utility construction coordinator, who would represent the DOT. This project would focus on determining cost and time effectiveness of an onsite utility construction coordinator, any barriers to implementation, the necessary training and certification of the coordinator, and the available training delivery methods.

Utility Conflict Identification and Solutions

Determining the exact three-dimensional location of a utility is a prudent but inexact activity. Regardless of how a utility's location is determined, conflicts during design exist in most projects. Some states have general criteria for how to identify potential conflicts. This project would identify the existing formats used in state DOT utility conflict matrices, develop guidance tools, and develop complete utility matrix formats that incorporate the guidance tools.

Subsurface Utility Engineering (SUE) Qualifications

The Construction Institute of the American Society of Civil Engineers' (CI/ASCE) national engineering standard 38-02, the "Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data," is increasing the use of subsurface utility engineering. Some states do not have qualification standards for SUE engineers, and many that do are considering the need to upgrade them. This project would investigate DOT qualification programs and requirements for SUE consultants to develop requirements that demonstrate the competence of SUE firms and their ability to comply with CI/ASCE 38-02.

Model Certification Programs for Utility Relocation Coordinators
A utility relocation coordinator may be employed by DOTs, contractors, and utilities, although there is no standard for the utility relocation coordinator's qualifications. This project would develop core competencies that utility relocation coordinators need to address utility relocation issues in transportation projects, and develop corresponding model training and experience qualification criteria. The project would also investigate the feasibility of a national certification process for utility relocation coordinators.

Follow-on Project R15-B

To continue research that can lead to the resolution of utility conflicts, SHRP 2 created project R15-B: Identification of Utility Conflicts and Solutions, which is currently active. The objective of the project is to create tools and methodology that public agencies and utilities can use to identify and resolve utility conflicts, and thus improve the project development process.

The R15 research was conducted and a report was prepared by the research team consisting of Marie Venner of ICF International, Fairfax, Virginia, and Ralph Ellis and Kathleen Vandenbergh of The University of Florida, Gainesville, Florida, with support from Ginger Adams of Advantage Facilitation, Ft. Collins, Colorado, and Jim Anspach of So-Deep, Manassas Park, Virginia.

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SHRP 2 Staff for Renewal: A. Robert Raab, Senior Program Officer; James W. Bryant, Jr., Senior Program Officer; Monica A. Starnes, Senior Program Officer; Noreen Stevenson, Senior Project Assistant.

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A SHRP 2 Renewal Project Brief

Managing Utility Conflicts to Achieve the 3 C's

Communication, Coordination, and Cooperation

APRIL 2013

When utility relocation is involved, highway construction projects often take longer and cost more. Identifying and resolving potential utility conflicts early in the design process can minimize these delays and costs. Research from SHRP 2's Renewal focus area (Identification of Utility Conflicts and Solutions Project R15B) developed a comprehensive approach and tools that public agency and utility professionals can use to resolve and manage utility conflicts with new efficiency. The tools developed include two utility conflict matrices (UCMs) that enable users to organize, track, and manage the conflicts that frequently arise: (a) a prototype UCM in Microsoft Excel, which has a main utility conflict table and a supporting worksheet to analyze utility conflict resolution strategies; and (b) a prototype utility conflict data model and database, which is a scalable UCM that provides the tools of a database environment for conflict management. This project also developed a 1-day training course to instruct end users on how to adopt the tools, strategies, and guidelines that include specific steps to start and continue implementation. This brief gives an overview of the products.

Leif Skoogfors/FEMA

Utility Conflicts

Two critical factors that contribute to inefficiencies in the transportation project development process are the lack of accurate, complete information about utility facilities that might be in conflict with the project and the resolution and overall management of those conflicts. These factors can cause a variety of problems:

- Disruptions when utility installations are encountered unexpectedly during construction, either because there was no previous information about those installations or because their stated location on the construction plans was incorrect;
- Damage to utility installations, which can disrupt utility service, damage the environment, and endanger the health and safety of construction workers and the public; and
- Delays that can extend the period of project development or delivery and increase total project costs.

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The traditional approach for resolving utility conflicts at many state departments of transportation (DOTs) is to relocate the affected utility facilities—often at great expense to the utility owner or the DOT or both. Relocating a utility facility is not necessarily the only or best strategy to resolve a utility conflict. Other strategies include designing and constructing the transportation facility in such a way as to leave the affected utility facilities in place. This option requires effective management to avoid design changes with negative impact on costs and schedules.

Practices involving the use of UCMs to organize, track, and manage utility conflicts vary widely across the country and some are more successful than others. Recognizing that transportation agencies could deliver projects faster with streamlined and widely-accepted processes for resolving utility conflicts, SHRP 2 Renewal Project R15B addressed this need in the following ways:

- Reviewing trends around the country and identifying the best practices on the use of UCMs,
- Developing and testing a standardized UCM concept,
- Developing training materials, and
- Developing implementation guidelines.

Prototype 1: Utility Conflict Matrix

Prototype 1 is a stand-alone product in Microsoft Excel format that includes a main utility conflict table and a supporting worksheet to analyze utility conflict resolution strategies. Used most simply, Prototype 1 provides a basic, convenient mechanism to list all utility conflicts associated with a project. However, for maximum benefit, the UCM can be used in conjunction with the alternative conflict resolution subsheet to identify, document, and track optimum utility conflict resolution strategies.

Oregon Department of Transportation


Liz Roll/FEMA

Gas company employees repairing a utility line on a road in Alexandria, Virginia

The training materials include a lesson with a hands-on exercise that describes an example process for documenting utility conflicts and identifying and comparing conflict resolution strategies using the UCM and the utility conflict resolution subsheet. The basic process is summarized as follows:

- Identify and list all potential conflicts in a project. This activity is continuous throughout the utility conflict management process. Use a separate line for each utility facility that may be in conflict at the same location. For example, for a conflict location that involves a water line and a gas line, create one record for the water line and a second record for the gas line. Assign a unique utility conflict ID to each record.
- Complete the UCM up to the column that identifies the type of utility investigation needed.
- For each conflict, determine the type of utility investigation needed.
- Collect utility data at the appropriate quality level (QLD, QLC, QLB, or QLA).
- For QLA data, add the test-hole number associated with the utility conflict(s) in question.
- Analyze potential conflict resolution strategies for each utility conflict record. If the available information is not sufficient to make a determination, it may be necessary to collect additional data. In this case, use the recommended action or resolution column to document the need for additional data collection.

- Use the conflict resolution subsheet to analyze and document the advantages, disadvantages, costs, feasibility, and decision of each alternative resolution considered.
- For the selected conflict resolution strategy, complete the recommended action or resolution, estimated resolution date, and resolution status cells in the UCM. This activity is iterative.
- Populate the control fields (name and date) at the top of the UCM.
- Create a historical record of UCM changes by saving the UCM under a different file name each time the information in the table changes.


George Armstrong/FEMA

Prototype 2: Utility Conflict Data Model and Database

Prototype 2 is a scalable UCM type that enables utility conflict management in a database environment. To facilitate implementation, the research team used industry-standard protocols in developing the data model (including a logical model, a physical model, and a data dictionary). The data model is in AllFusion ERwin Data Modeler format, which can be exported to databases such as Oracle and SQL Server. The prototype data model and the corresponding database in Microsoft Access format were tested using data from sample utility conflict tables from across the country.

Implementing a database for managing utility conflict data requires careful planning, experienced staff, and buy-in from multiple parties. The effort required to implement a database system is considerably higher than implementing a stand-alone spreadsheet. However, a database approach offers a multitude of advantages and benefits that a spreadsheet cannot offer.

The prototype database structure was based on a large number of state DOT UCMs and many diverse data items, and as a result, the prototype data model and resulting database are flexible and capable of accommodating most data items related to utility conflicts. This flexibility was proven through the process of replicating the sample UCMs described in the final report. Additionally, the prototype data model and database used standard database design principles to address the needs of a wide range of state DOTs, including linking to existing database systems to avoid data duplication. Further advantages of a database approach to managing utility conflicts include the following:

- The database can be adapted to address changes in DOT needs and business processes.
- The DOT can choose to implement all or selected portions of the complete system.
- The database is scalable to allow access by many users and store large datasets.
- Look-up tables can be easily expanded as needed to accommodate data items and descriptors unique to the DOT.
- The database can link to existing DOT data systems.

Once a database system is implemented, its real power lies in its ability to enable a wide range of queries and reports. In addition to the various UCMs replicated during the research, a short sample of reports the prototype database could enable includes the following:

- A report listing all utility conflicts associated with a company (for a specific project, corridor, or time frame);
- A report of all water facilities in conflict (for a specific project or corridor);
- A report summarizing average conflict resolution times for electric facilities statewide;
- A report providing average conflict resolution times for water facilities on project Z;
- A report listing all utility conflicts with resolution times of more than 100 days;
- A customized UCM report listing only the utility conflicts of a specific utility owner; and
- A listing of unresolved utility conflicts at time of letting for inclusion in the plan, specifications, and estimate package (sometimes called utility certification).

Utility Conflict Matrix Training Course and Pilot Tests

The training course includes a lesson plan and presentation materials to assist with the dissemination of research findings. Designed for a total of 7 hours and 15 minutes of instruction, the 1-day UCM training course is divided into six lessons. The seminar provides numerous opportunities for participant interaction and enables the instructor to adjust session and lesson start times and durations, depending on the audience and the level of participant engagement in the discussions. The training materials use National Highway Institute standards and templates.

During the project, two pilot training sessions were held, one in Little Rock at the Arkansas State Highway and Transportation Department and one in Pierre, South Dakota, at the SDDOT headquarters. In total, about 50 people participated in the two pilots, including representatives from federal, state, and county agencies with experience in project development, design, right-of-way, and utility coordination. More information about the training and the pilots is available in the final report.

SHRP 2 Contact

The SHRP 2 contact for this project is James Bryant, who can be reached at jbryant@nas.edu.

Product Availability

Identification of Utility Conflicts and Solutions (SHRP 2 Report S2-R15B-RW-1), the prototype UCMs, and the training materials are all available online at http://www.trb.org/Main/Blurbs/166731.aspx.

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STRATEGIC HIGHWAY RESEARCH PROGRAM

PROJECT BRIEF R16 JANUARY 2010

Renewal Project R16: Railroad-DOT Institutional Mitigation Strategies

This document is drawn from the final report prepared by researchers for Project R16. The objectives of this project were to: identify strategies and institutional arrangements that will facilitate beneficial relationships between railroads and public agencies; investigate and develop innovative partnering techniques; develop a draft model agreement and streamlined permitting processes; and identify barriers that impact effectiveness and propose remedies. The final report includes eight model agreements that can be modified to meet the legal requirements and accepted contracting processes of individual agencies and railroads. The Responsible Staff Officer for this project is Monica A. Starnes, who can be contacted at mstarnes@nas.edu.

North American railroads and public highway departments interact thousands of times annually as the highway agencies conduct projects that cross or abut railways. Each interaction requires mutual agreement and a thorough review of the safety, engineering, and operating effects that the project will have on the railroad during construction and for decades thereafter. Although most of these reviews and agreements proceed smoothly, the highway agencies and the railroads agree that delays and problems occur routinely. These delays can cause important highway projects to increase in cost and they can consume valuable staff time and engineering resources of all parties.

This project provides model standard agreements, standard processes, and best practices that can help both sides reduce the time and cost of project reviews. To succeed, each side must understand the basic needs of the other and both must have common languages, practices, standards, and expectations. Although both highway agencies and railroads are driven by engineering factors to make investment decisions about linear transportation facilities, they approach their decisions from very different perspectives.

Understanding the Railroad Perspective

A brief history of the railroads' recent past can help explain their approach to public projects. Although much smaller in terms of employees, the North American railroads today are operating at unprecedented levels of volume, efficiency, and reliability. This success has come after decades of deregulation, downsizing, consolidations, and shareholder demands for increased efficiencies and profitability. As a result, railways are more heavily travelled than ever in their history, while the railroad staffs are at their smallest. Dramatic downsizing in recent decades has led to a reduction in non-core staff. Many have outsourced their engineering departments, which formerly addressed public projects. The railroads cannot tolerate delay to their

operations and are unwilling to accept risk or constraint to their finite and ever-more-valuable rights-of-way.

The railroads' approach to public projects is dominated by several overriding factors:

- Public highway projects seldom benefit the railroads;
- Highway projects can constrain future rail capacity;
- Construction activities can create great risk to workers, railway equipment, and track operations;
- Railroads cannot tolerate train delays on tightly strung national corridors; and
- Railroads must cover all of their costs, including engineering reviews and construction monitoring.

Understanding the State Perspective

The state and local highway agencies are the mirror image of the railroads when they approach highway-railroad projects. Highway agencies are public entities, accustomed to providing advice and reviews without cost. Their personnel focus on the public's expenditures and try to reduce the cost of bridges and other projects whenever possible. Highway agencies have long lead times for planning, developing their projects with years of analysis as opposed to railroads, which make capital decisions annually.

Dozens of state and local highway agencies were consulted and their commonly expressed needs from the railroads include:

- Timely and reliable reviews;
- Better internal railroad coordination;
- Improved mechanisms for access to rights of way;
- Consistent design requirements; and
- A spirit of cooperation and recognition that public agencies have limited time and resources to accommodate railroad needs.

Findings

The following key findings hold promise for improving the agreement and engineering review process.

Few metrics exist. A common issue throughout this research is a lack of common baselines of performance. It appears that there are no widely recognized standards for performance in conducting railroad reviews, agreements, or approvals. In fact, few states could produce metrics on their own project submittals to determine how many projects fail to receive a review or an approval within an agreed-upon timeframe. A few states have developed master agreements that include desired review times but those appear to be in the minority. As a result of this lack of baseline information, the reporting of best practices and the listing of recommendations are based upon the informed consensus of the practitioners, and not the empirical observation of performance.

Pressures on both sides will increase. Railroad traffic is projected to steadily increase because of international trade, long-term economic and population growth, and the expansion of intermodal traffic. The recession of 2008 depressed rail traffic but as a long-term trend, rail volumes are predicted to grow. The existing and finite rail corridors will become busier, more congested, and even less tolerant of delays or encroachments. Neither side can expect a lessening of pressures to manage project reviews efficiently.

Both sides agree on best practices. On the positive side, however, the highway agencies and railroads have identified more than 20 best practices that expedite the review process. The productive and complementary examples illustrate practices drawn from "partnering," good project management strategies, and the type of "process improvement" efforts common in frameworks such as Six Sigma, the Baldrige process, or "environmental streamlining." As with the streamlining best case examples, both parties have enumerated their requirements and have jointly identified practices and processes that both satisfy the requirements and advance highway renewal projects.

These best practices include:

- Early formal coordination while project concepts are still under development;
- Periodic, on-going reviews throughout the project's development;
- Open, continuous lines of communication;
- Escalation procedures to resolve conflicts;
- Common, consistent, and empowered points of contact in both agencies who can make decisions and remove bottlenecks;
- Regular process-review meetings where both sides identify issues and strategies to address

them;

- Standard, streamlined agreements to address recurring issues such as insurance, rights of entry, liability, easements, safe construction practices, and on-going maintenance;
- Commonly understood design standards and construction practices agreeable to both parties;
- Training for designers and construction and maintenance personnel who interact with railroads; and
- Standard process manuals to follow in developing projects or conducting maintenance activities near railways.

Both sides identify some common problems. The highway agencies and railroads independently cite some common problems that they believe need to be addressed to everyone's mutual interest. Some of these are:

- The inability to reimburse engineering review costs early in the lifecycle of a project, even before the project is programmed or under development;
- The cost and availability of insurance; and
- Right-of-way appraisal processes for railroad easements that can be restrictive or contentious.

Partnering is a strategic opportunity. Another strategy that could be helpful to the agreement process is "partnering." This process was first articulated by the U.S. Army Corps of Engineers in addressing its large civil works projects. It also has been encouraged by the Federal Highway Administration, some state departments of transportation, and their associated contracting companies. In partnering, both parties:

- Define what a successful outcome would be;
- Formally agree that each wants to assist the other in achieving this common success;
- Develop a level of service agreement that clarifies what each expects from the other in terms of service and timeliness;
- Identify escalation paths for occasions when problems cannot be resolved at the lowest level;
- Agree to remain in constant communication to ensure that problems are identified early and to monitor whether milestones have been achieved; and
- Periodically analyze what went right, what went wrong, and what can be learned for the future.

Recommendations

The report recommends that highway agencies and railroads to review the best practices, model processes, and model agreements. Then they can self-assess whether any of the following actions might assist them in streamlining the agreement process including:

- Negotiate a memorandum of understanding between the highway agency and the railroad as to how they desire to conduct the review process, including periodic process-improvement efforts;
- Develop draft model agreements and streamlined permitting language;
- Adopt a "continuous improvement" framework to the agreement process so that both the highway agency and the railroad are tracking performance, and regularly conferring on ways to improve it; and
- Participate in efforts through their professional associations to continue dialogue on ways to share best practices and perpetuate the further development of model agreements and model practices.

This research was produced by Gordon Proctor & Associates, Inc., in association with StarIsis, Corp. and Michael Bradley and Associates. The Principal Investigators were Gordon Proctor and Shobna Varma. Both were assisted by Michael Bradley.

The Technical Coordinating Committee for Renewal Research in SHRP 2 oversaw the conduct of the research that is the basis for this Project Brief. The committee membership includes **Randell H. Iwasaki**, California Department of Transportation; **Rachel K. Arulraj**, Parsons Brinckerhoff, Inc.; **Michael E. Ayers**, American Concrete Pavement Association; **Thomas E. Baker**, Washington State Department of Transportation; **John E. Breen**, University of Texas, Austin; **Daniel D'Angelo**, New York State Department of Transportation; **Steven D. DeWitt**, North Carolina Turnpike Authority; **Rocco A. DePrimo,** Keith and Schnars, Pennsylvania; **Thomas Donovan**, California Department of Transportation; **Alan D. Fisher**, Cianbro Corporation; **Michael Hemmingsen**, Michigan Department of Transportation; **Bruce V. Johnson**, Oregon Department of Transportation; **Leonne Kavanagh**, University of Manitoba; **Thomas W. Pelnik, III**, Virginia Department of Transportation; **Mary Lou Ralls**, Ralls Newman, LLC; **John J. Robinson, Jr.**, Pennsylvania Department of Transportation; **Michael M. Ryan**, H. W. Lochner, Inc.; **Clifford J.**

Typical Master Legal Agreement Provisions			
Whereas both parties routinely process payments for engineering reviews	Parties agree to authorize PE within 30 days of notification of RR	No contractors or department employees can proceed without written railroad approval	RR will provide right of entry for PE and construction activities with due notice
Whereas both need to agree on numerous and similar project agreements	Department agrees to select consultants experienced with specific RR	Department will ensure insurance provisions will be met by contractor	RR will make all reasonable efforts to accommodate contractors
Whereas, it is in interest of taxpayers and shareholders that both entities economize	RR agrees to 60 day reviews on PE submittals	Department will provide 30 days notice of flagging needs. RR will make all reasonable attempts to provide flagging	RR will specify operating envelop and construction windows
Both want safe, efficient highway and railroad operations	RR agrees to keep thorough records for invoicing of PE expenses	Plans affecting RR will require approved safety training for contractors	A separate right of way agreement will be developed if needed
Therefore they want a Master Agreement to standardize the legal review process	Department agrees to 30 day prompt payment of complete invoices	All plans will require preconstruction meeting to be offered to RR	A post-construction meeting will be offered to RR
Define Preliminary Engineering	Both parties will agree to standard PE rate schedule	All plans will note the railroad's control of the project site and its ability to direct contractor in issues relating to safety and train operations	Separate project agreement will address maintenance agreement
Agree to develop a standard PE Agreement	Both agree to abide by Title 23 eligibility	All plans will note the contractor will abide by all RR utility and right of way agreements	30 days notice will be given RR for maintenance right of entry needs
Department agrees to give timely notice of intention to develop a project	PE approval does not constitute project approval or participation	Plans will note that RR has right to inspect and approve all work affecting RR	RR will keep and provide auditable, complete records
		The parties shall indemnify the other for individual negligent liability and will share joint liability.	Department will attempt 30 day prompt payment of RR expenses

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