



U.S. Department of Transportation
Federal Highway Administration

AASHTO



2017 IMPLEMENTATION HIGHLIGHTS
**ADVANCING THE STATE
OF THE PRACTICE**



Working in Partnership

The second Strategic Highway Research Program (SHRP2) is a partnership of the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and the Transportation Research Board (TRB). TRB completed the research, and now FHWA and AASHTO are jointly implementing the resulting SHRP2 Solutions that will help the transportation community increase safety, enhance productivity, boost efficiency, and improve the reliability of the nation's highway system.

www.fhwa.dot.gov/GoSHRP2 ■ <http://SHRP2.transportation.org>



U.S. Department of Transportation
Federal Highway Administration

AMERICAN ASSOCIATION
OF STATE HIGHWAY AND
TRANSPORTATION OFFICIALS
AASHTO

Advancing the State of the Practice



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The second Strategic Highway Research Program (SHRP2) implementation program, created through a partnership between the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO), experienced another successful year in 2017.

To date, SHRP2 has produced 63 solutions that have been implemented in the field to solve various transportation challenges, all from the initial research phase. Through the total \$155 million in funding assistance granted in all 50 states, the District of Columbia, and Puerto Rico, these solutions are being implemented around the country to advance our industry. Nearly 305,000 individuals have been engaged in the program through peer exchanges, workshops, and training. SHRP2 continues to showcase the benefits of implementing new and innovative solutions within the field of transportation.

This report highlights some of the most interesting and compelling stories emerging from SHRP2 implementation in 2017, and yet these stories represent just a fraction of the innovative solutions coming out of SHRP2. While not every SHRP2 solution will work for every agency when combatting those challenges, the implementation of these innovations allows us to continue striving for excellence and to keep advancing the state of the practice.

SHRP2 has up to this point focused largely on the Implementation Assistance Program (IAP) that provides funding and technical assistance for agencies testing out these innovative solutions. Aside from product implementation and adaptation, SHRP2 has benefited the field in other ways. The SHRP2 Education Connection, established in 2015, is an initiative to help the next generation of transportation professionals succeed through SHRP2 Solutions while still in school. This program gives our young transportation scholars a chance to work with cutting-edge solutions on some real-world problems they will encounter during their careers. SHRP2 has also provided state departments of transportation, metropolitan planning organizations, and other regional and local agencies with valuable peer-to-peer exchanges, which has resulted in countless new partnerships and learning opportunities.

Implementation of SHRP2 remains in full swing until all projects finish up over the coming year. However, we will be seeing the impact of these implementation efforts long past that date. In addition, the program has already proven successful and accomplished in many cases what we hoped it would—finding new solutions to some of our most difficult issues and saving our transportation agencies money and time, while making everyone safer on our transportation systems.

This report will provide deeper insight into SHRP2's lasting impact. This will not be the last you hear of SHRP2 successes, as we know the program has forever changed the transportation landscape.



SAVE LIVES

SHRP2 Solutions make our roads safer by helping to reduce worker and driver exposure to dangerous construction zones, incident scenes, and congestion.



SAVE MONEY

SHRP2 Solutions decrease construction and maintenance costs with innovations that lead to longer-lasting infrastructure, provide for more efficient project planning, and speed project delivery.



SAVE TIME

SHRP2 Solutions speed project delivery, decrease congestion on the highway system, and make travel times more reliable, saving everyone time on the nation's roadways.



SHRP SOLUTIONS ARE:

- Products developed from objective, credible research.
- Solutions that respond to transportation community challenges – safety, aging infrastructure, congestion.
- Tested products, refined in the field.

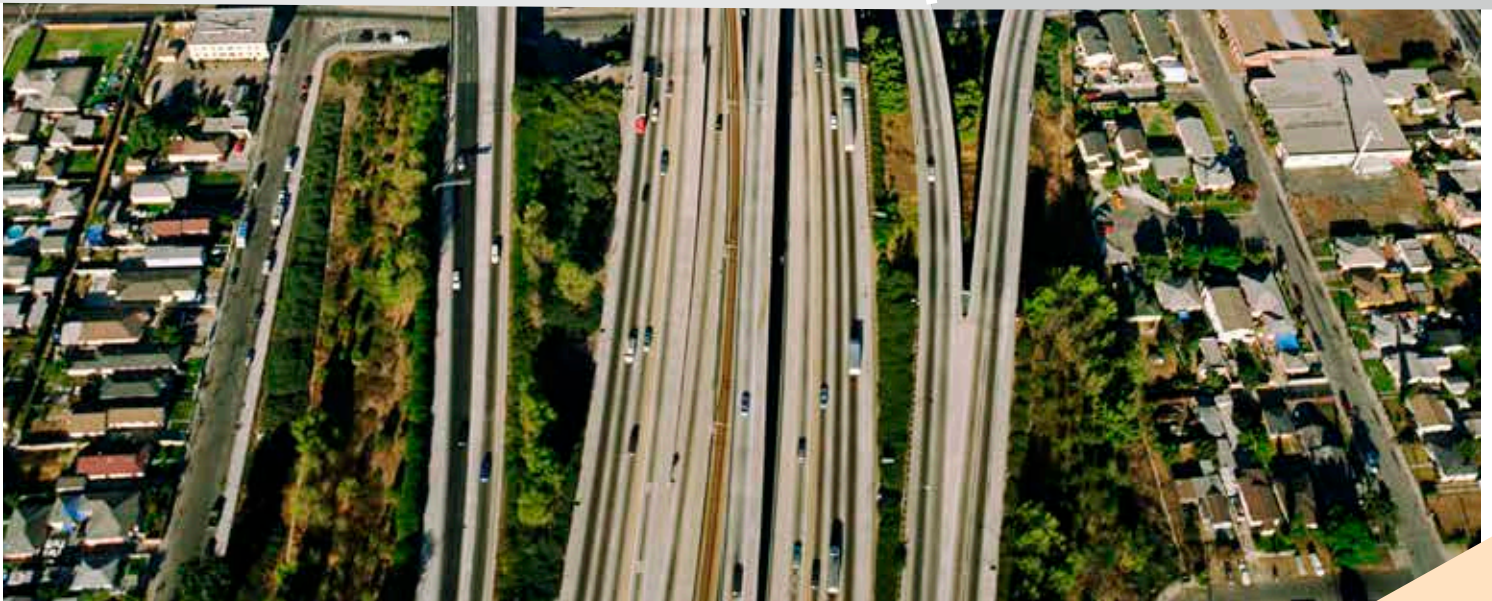
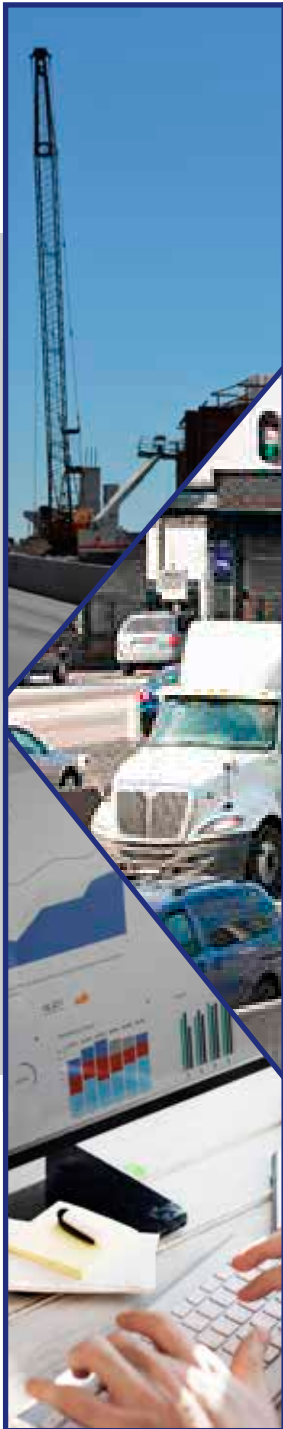


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SHRP2 OVERVIEW

FOCUSING ON RESULTS

The nation's transportation systems rely on innovative techniques and new approaches to meet the needs of its users. The implementation of the second Strategic Highway Research Program (SHRP2), a partnership between the FHWA and AASHTO, was created to foster such innovations in order to allow the transportation community to save lives, money and time. SHRP2 products have all emerged from objective research, now being tested and implemented by transportation agencies to make transportation systems better, stronger, and safer.

These SHRP2 products have the potential to change how transportation agencies plan for, design, build, and operate the nation's transportation systems. At a glance, the SHRP2 products born from this program have given agencies:

- Cost-effective bridge designs for faster, longer-lasting replacement
- Pavement preservation techniques for high-traffic roadways
- Methods to improve operations and extend capacity
- Innovative strategies for managing large, complex projects
- Planning techniques for conserving green spaces and protecting the environment
- Training for fast, multi-agency response

All SHRP2 products are housed under one of four SHRP2 focus areas:

Reliability, Renewal, Capacity, and/or Safety. This report will highlight a few of the most interesting stories coming out of each focus area.

✓ Safety

Safety is always at the forefront of transportation agencies. Under this focus area, SHRP2 sought to make our roads safer by compiling data to improve highway safety, creating tools for data analysis, and utilizing state-of-the-art safety technologies on the road and in vehicles. With these tools, SHRP2 safety solutions will make our nation's roadways safer for both system users and workers.

✓ Renewal

Renewal SHRP2 products offer transportation agencies tools to renew and improve transportation systems at a lower cost and in a more efficient manner. These products include solutions that repair and replace bridges faster, design longer-lasting bridges, allow for a more accurate inspection of concrete bridge decks and tunnel linings, help better detect and manage utility conflicts, and design and build lower-cost, longer-life pavement systems.

✓ Capacity

SHRP2 products under the Capacity focus area allow transportation systems to grow and expand in a smarter way. These products include solutions that help agencies through better decision-making,





the incorporation of multi-modal alternatives into planning at earlier project development stages, building greater public trust through more transparency, and, most of all, expedited project delivery through more accurate modeling techniques, more predictable (and better) permitting, and greater input, earlier in the process.

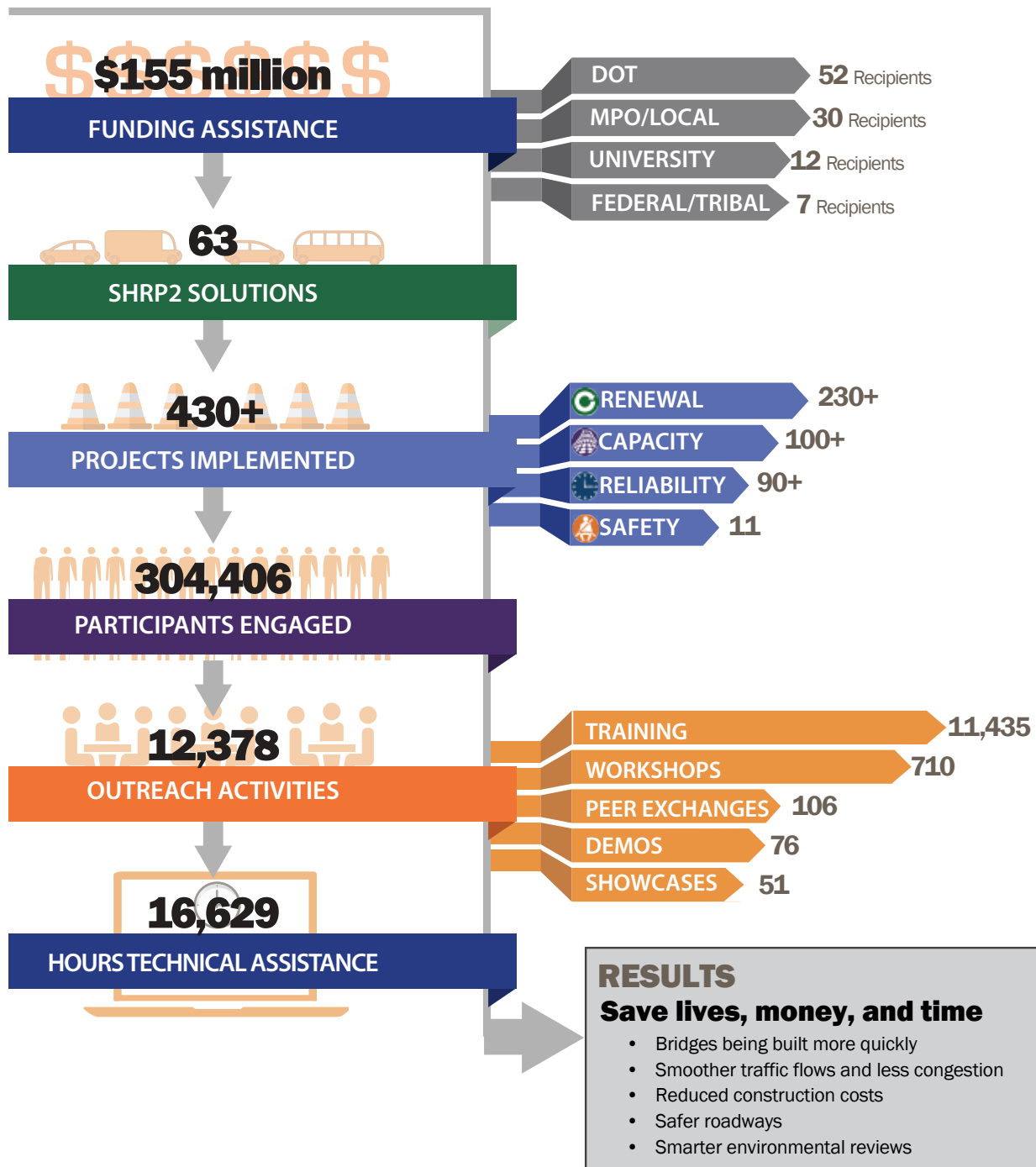
✓ Reliability

Innovations and strategies in SHRP2's Reliability suite of products focus on improving the dependability of transportation systems and building stronger operational capabilities, saving time and money, while making systems safer. This is done through SHRP2 products that provide relief from unexpected congestion, improve highway management processes, build a network on which users can count, provide safety and coordination for first responders, and maintain and provide relevant resources to adapt and improve transportation system operations on a regional level.

Each SHRP2 product falls under one of these focus areas, but they all intersect and often overlap. While the program is administered by FHWA and AASHTO, it is an effort that relies on partnerships and the participation of so many others, including state DOTs, many other transportation agencies, and our industry partners.

From Research into Practice: SHRP2's Implementation Progress

 <p>RENEWAL Enabling faster, minimally disruptive, and longer-lasting infrastructure improvements.</p>	 <p>RELIABILITY Championing predictable travel times.</p>	 <p>CAPACITY Working to build greater collaboration in transportation decision making.</p>	 <p>SAFETY Seeking to identify the behaviors that cause and avert collisions.</p>
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The data shown here and throughout this report are as of November 1, 2017.

SAFETY

Identifying the behaviors that cause and avert collisions



Nowhere is the importance of fact-based information more evident than in the transportation field. Good data gives us the ability to improve mobility, increase efficiency, and enhance safety by giving us a window into how the built environment works and where physical improvements can offer the greatest benefit. Historically, the safety and design manuals that transportation agencies used to develop and improve our infrastructure were solely based on crash history and engineering research, and their focus was on how roadway characteristics and the configuration of roadside hardware can prevent crashes. However, as well-researched as they are, the current safety guides and manuals do not take into account the most decisive element in more than 90 percent of crashes: the human factor.

“The ultimate vision for the SHRP2 Safety focus area is to significantly improve highway safety,” noted Aladdin Barkawi, the SHRP2 Safety focus area implementation coordinator. “The whole point of our effort is to obtain and integrate behavioral data—this is the missing piece when it comes to figuring out why crashes occur. We can figure out the engineering aspect of why crashes occur, but we need to significantly improve our understanding of driver behavior for planning, operations, and safety so that we can increase our chance of achieving zero deaths and significantly reduced severe crashes on our nation’s roadways.”

Defining the Human Factor

To fill this gap in understanding how drivers interact with the roadway, SHRP2 conducted a Naturalistic Driving Study (NDS) that included more than 3,300 instrumented vehicles and more than 3,500 participants across six locations. To provide context for those activities, however, researchers would also need an understanding of the roadways, intersections, interchanges, and other elements that drivers encounter during their trips, so SHRP2 initiated an effort to design, build, and populate a Roadway Information Database (RID)

to collect data on the roads most frequently driven by NDS participants.

Over a two-year period, the study collected more than two petabytes of continuous data.

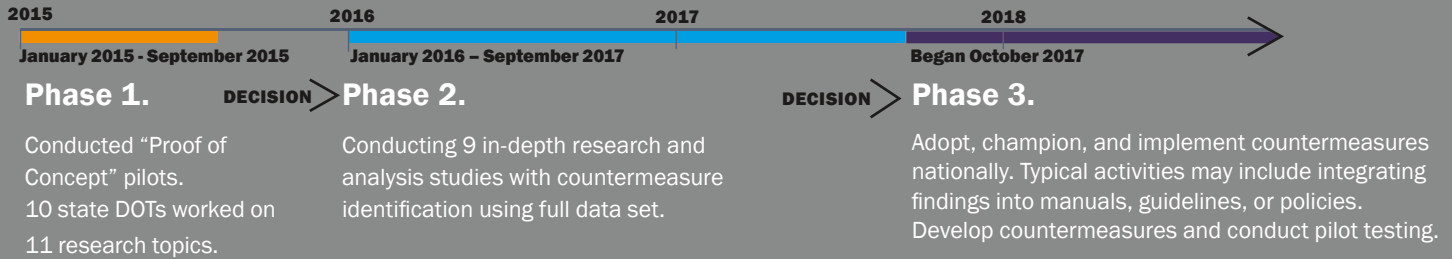
The NDS and RID together provide a means of assessing the changes in collision risk associated with both physical roadway factors and how drivers interact with them. The full datasets are held in two secure data enclaves: one at the Virginia Tech Transportation Institute and the other at the Turner Fairbank Highway Research Center’s Safety Training and



Two petabytes of data are equivalent of about 500 billion pages of text, enough to fill 40 million four-drawer filing cabinets.

Analysis Center (STAC), which was designed and built specifically for that purpose. The STAC, which opened its doors in December 2016, offers researchers extensive opportunities to work directly with this immense collection of data. In addition, selected data sets are continuously being made available to qualified researchers through InSight, a website that allows researchers to access the NDS/RID data in pursuit of specific research questions.

THE SAFETY IAP STUDIES INCLUDE RESEARCH CONDUCTED IN THREE PHASES.



The popularity of the data available through InSight is growing as word of its breadth spreads across the research community. As of September 2017, more than 230 active data use licenses—more than double the number in use in 2016—are being used to study a range of issues using the NDS/RID data. The SHRP2 implementation team expects the results of this research to lead to the development of new safety

countermeasures and new standards founded on roadway characteristics and human factors. “The results of this research will provide transportation practitioners with new ways of doing things so they can be more effective. What comes out of this program is what’s going to influence us in the transportation field to do better,” noted Barkawi.



SAFETY

The SHRP2 research and implementation on work in the Safety focus area has yielded two powerful databases, the naturalistic driving study (NDS) database and the roadway information database (RID). Their data helps the transportation community better assess the role of drive behavior in more than 90 percent of crashes in the United States. Potential countermeasures that can be developed using the SHRP2 Safety data have the potential to save thousands of lives annually.

The Naturalistic Driver Study (NDS) is the largest of its kind anywhere in the world.

49.7 million vehicle miles

3,147 drivers all age/gender groups

RESEARCH AREA AND # OF LIVES THAT COULD BE SAVED

Roadway Departure	18,275	Speeding	10,497*
Horizontal/Vertical Curves	9,500	Work Zones	700
Interchanges	6,762	Roadway Lighting	14,000
Adverse Weather	5,897	Pedestrian Safety	5,987*

Figures represent the number of fatalities by category as compiled by the FHWA, National Highway Traffic Safety Administration, the National Safety Council, the National Work Zone Safety Information Clearinghouse, and the Pedestrian and Bicycle Information Center.

*Data source: Speeding: NHTS, 2016; Pedestrian Safety: NHTSA.

The Roadway Information Database (RID) includes:



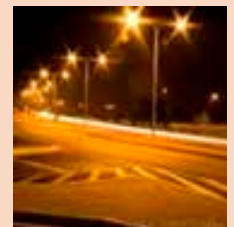
Horizontal curvature: curve start, end, direction, length, and radius



Number of lanes



Median; type of median, shoulder width



Roadway lighting & rumble strips

Data source: FHWA, NHTSA National Center for Statistics and Analysis National Work Zone Safety Information Clearinghouse

SAFETY FEATURE STORIES

Connecting to the Future – Turning Research into Reality



One effort that has shown particular success to date and has broad applications beyond the scope of the current research is the work being done by the Wyoming Department of Transportation (WYDOT) and its partners at the University of Wyoming. Their work has been part of the SHRP2 IAP Safety research. The Wyoming team is using the SHRP2 NDS data to identify driver behavior and performance characteristics during adverse weather conditions in an effort to improve the algorithms used by variable speed limit (VSL) systems during periods of inclement weather. As with many other areas of transportation research, while the effects of adverse weather on safe and efficient operation of transportation networks have been studied extensively, data about driver activities and performance during challenging weather conditions are noticeably absent.

“We are trying to understand how drivers are actually behaving during adverse weather conditions—how they choose speeds, change lanes, follow each other, and what kind of gap and headway they maintain,” explained Mohamed Ahmed, Ph.D., P.E., who is leading the University of Wyoming research team. “We also want to see what factors contribute to weather-related crashes and near crashes,” he added.

This research is particularly important to Wyoming, which is host to more than 400 miles of Interstate 80 (I-80), a major east-west shipping route. The section of interstate that runs through Wyoming carries 32 million tons of freight per year and plays a vital role in the state’s economy. The high volume of truck traffic combined with extreme seasonal weather, however, often creates dangerous driving conditions.

One of the methods Wyoming uses to reduce crashes on the I-80 corridor is variable speed limits (VSL), which have been used successfully in the state since 2009. VSLs have been proven to increase safety during adverse weather by slowing speeds and reducing the variation in speed among drivers, who often have different perceptions of the severity of weather conditions and the behaviors that constitute risky driving. The focus of Wyoming’s research is on incorporating human behavior into the VSL control logic, explained Tim McDowell, P.E., the state programming engineer for WYDOT. “Right now, the VSL logic is primarily based on physics and observed environmental factors—in other words, weather,” he added. “We want to improve on an already successful application by adding actual human behavior.”

Notably, the 137 miles of VSL corridors are located on the same roadway where WYDOT’s Connected Vehicle Pilot deployment is taking place. This is also contributing to advances because researchers have access to better data through that pilot, Dr. Ahmed explained. “We have instrumented snow plows that are collecting weather data, not just the road weather information system on I-80. We also are getting real-time data from instrumented trucks, plows, and other research partners. Therefore, the connected vehicles team, led by Vince Garcia at WYDOT, will get better data from that program, and in turn, improved VSL and timely warnings will be disseminated to road users via connected vehicle human machine interfaces and smart phone apps.”

“Real-time data will be evident here within a year,” agreed McDowell. “The only thing we’re really missing is wind conditions. We get a lot of wind in Wyoming, and this whole northern tier of states sees a higher than normal amount of truck blowovers, so that’s going to tie into future research efforts,” he added, noting that the trucking industry has become one of the agency’s partners in this effort. “All this data is coming together to make this a safer route that’s more economically viable. We are very excited not just by the research but by the actual application of it.”

However, getting to this point, and even moving forward with real world applications, has not been without challenges, Ahmed explained. “In the beginning, one of the main issues was how to identify and extract adverse weather-related trips in the NDS. All the other SHRP2 research projects started with a specific research question using the RID data, then they looked for overlap with the NDS data. Our approach was different. We needed to find a way to identify adverse weather conditions rather than roadway features.”

“They told us they didn’t think we’d find that kind of information.” McDowell added. “We accepted the challenge, and the top-notch team at the University of Wyoming deserves a lot of credit for thinking outside the box.”

In the end, the study team used windshield wiper status to determine periods where rain events were likely taking place. Even this presented some initial hurdles due to the event coding methodology, but the challenge was resolved and the proof of concept for Phase 1 was a success. The Phase 2 research has expanded to include snow, fog, and adverse surface conditions by leveraging weather condition

data available through nearby environmental sensor stations and geographical information systems as well as by using weather-related crashes as crash sensors.

Although still underway, the Phase 2 effort has been so successful to date that WYDOT has begun to involve the transportation management center staff responsible for the state’s VSL system. By spring of 2018, work will begin to incorporate the research findings into the VSL algorithm to make it even more efficient and effective.

The Wyoming research will also have a broad impact nationally within the next few years. As part of the Phase 3 effort, the research team will begin contacting other state transportation agencies to learn about their practices for deploying and managing VSLs. “The old guidance and standards for VSL deployment is very dated, so we’ll see what the practices are in other states and how they can be improved based on what we’re learning from the NDS and the connected vehicles pilot as well,” McDowell noted, adding that FHWA was supporting the development of a national guideline for VSL deployment, operations, and management with additional funding.

An important parallel effort that may have nationwide impacts is the work underway to incorporate human factors into microsimulation models that address adverse weather conditions. At present, the research team is seeing good results related to integrating what has been learned into microsimulation tools. This effort has the potential to improve the ability of simulation tools across the board by accounting for human factors within those models that incorporate adverse weather conditions.

“Looking forward from the DOT point of view,” said McDowell, “there will be forms of this research that we will continue to use years into the future. We’ve had great results just by implementing VSL, but by continuing to improve VSL and how we manage, we will have a great safety asset that we will continue to use from here on.”



The Power of Data

The power of the NDS and RID data should not be underestimated, Aladdin Barkawi noted, adding that it has applications that are much more widespread than just within transportation. While these data have potential to advance the state of the practice within transportation planning, operations, and safety, they can also be leveraged in more diverse fields, such as manufacturing and even medicine.

The Centers for Disease Control (CDC) has determined that motor vehicle crashes are the leading cause of death in the first three decades of Americans' lives, making traffic safety a serious public health concern. As a result, CDC's Injury Prevention Center has designated motor vehicle injuries as one of its seven major focus areas. In 2016-2017, a study led by researchers from the Center for Injury Research and Prevention at the Children's Hospital of Philadelphia used NDS data to compare crash rates and rear-end crashes among novice teen drivers with crashes among experienced adult drivers.

"We all know from police reports that teen crash more than adults, but I wanted to understand why," said Dr. Helen Loeb, a lead researcher on the study. "What is it that they did wrong? We decided to look at on-road driving data the way we looked at driving simulator data: with a microscope. We wanted to understand how teens reacted in emergency situations. Our results showed that teens braked with a lot less pressure or urgency when they were presented with an emergency situation."

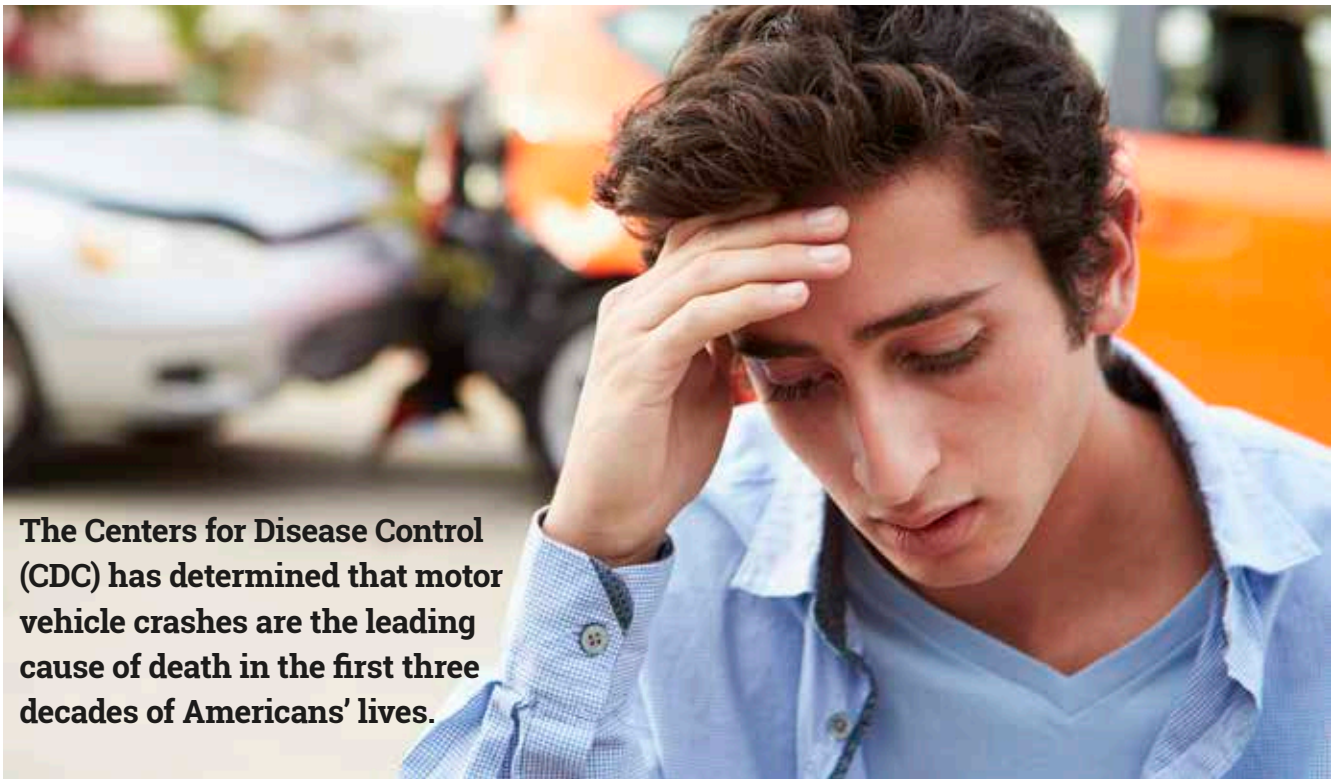
The study's findings were also revealing in other ways. For example, since many low impact crashes are never reported to the police, the study determined that the actual crash rate was a lot higher than the 3 to 4 ratio of teen crashes to experienced driver crashes that is usually reported; in fact, they found that the rear-end



crash ratio for teens is more than 7 times that of adults. For road departure crashes, this ratio surges to 14 times greater than that for adults when the exact mileage is accounted for. Unlike previous crash studies that focused on fatal crashes or police-reported crashes, however, the availability of detailed NDS data enabled the study to use a much more reliable methodology that was inclusive of all relevant at-fault crashes that occurred over a 3-year period among 1,140 novice teen and experienced adult drivers.

Dr. Loeb's research team suggests that these and future study results can be used to improve driver awareness of risks through more targeted outreach and education, improved simulator assessment for driving licensure, and potentially new licensure or enforcement-related policies for teen drivers.

She also notes that the depth and breadth of the NDS data spurred additional questions for potential future inquiry, including why unintended accelerations occur and how older drivers self-restrain (i.e., modify their driving by driving less or avoiding challenging situations in response to declining abilities) and if this is the result of a crash/near crash event. Understanding this phenomenon better could lead to identifying strategies for helping older drivers maintain independence and extend the period over which they can drive safely.



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A Multi-pronged Approach to Spreading the Word

In parallel with the SHRP2 research, the FHWA issued a Broad Agency Announcement (BAA) soliciting proposals for studies that would leverage SHRP2 Safety data to support transportation safety improvements. Across the eight projects selected for award, a total of 12 state transportation agencies were proposed as partners: Alabama, California, Iowa, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Virginia, Washington, and Wisconsin. Under Phase 1 of the BAA, the teams are exploring the application of the SHRP2 data to real-world highway research issues that have broad relevance in the areas of enforcement, speeding, intersection safety, work zones, and vulnerable road users, among others. The FHWA opted to use a BAA to fund these efforts because the BAA structure allows for and encourages diversity in the topic areas proposed. Notably, all of the projects are using methods that are applicable beyond their focus area, which means that these approaches can be applied to future research in other areas as well.

Beginning in 2017, efforts to expand the use of the SHRP2 databases continued with the launch of a new FHWA-led SHRP2 Naturalistic Driving Study Pooled Fund. The goal of this effort—which is a joint undertaking by the FHWA Offices of Operations, Planning, and Safety—is to advance the development of implementable solutions for state and local transportation agencies with an expanded emphasis beyond safety and into the areas of transportation operations and planning. Depending upon the yet-to-be-established research priorities, projects could include the development and improvement of countermeasures, predictive models, and design guides; new performance measures; and policy recommendations.

The pooled fund will be an important way to support state agencies by introducing them to the power of the SHRP2 Safety databases, according to Charles Fay, the pooled fund project manager. “If you look at the *Highway Safety Manual*, the predictive models used have no ability to take into account driver behavior. This will be what the pooled fund study will focus on,” said Fay. “The important thing about this pooled fund is that even though it’s led and managed by FHWA, the focus is on trying to advance the development of implementable solutions that transportation agencies can actually use.”

RENEWAL

Enabling faster, minimally disruptive, and longer-lasting improvements.



The SHRP2 research and implementation work in the Renewal focus area have yielded **20 implementable solutions** aimed at addressing a wide range of challenges. Based on the “Get in, get out, and stay out” philosophy, these solutions are changing how agencies manage aging infrastructure through rapid design and construction methods that cause minimal disruption and produce long-lived facilities.

SHRP2 Renewal research filled gaps in research and development to produce user-friendly tools so innovative design and construction methods can be applied more broadly. SHRP2 researchers and early implementers tested and objectively evaluated alternative methods to provide transportation agencies with information they need to deliver projects faster. Renewal research products simplified access to information on successful practices in many areas, including performance specifications, utilities, and interaction with railroads, which can speed project delivery and address causes of delay.

As a result, SHRP2 has produced 20 implementable Renewal solutions that have been used on more than 230 projects in the 50 states, Washington, D.C., and Puerto Rico through the Implementation Assistance Program. Beyond that, SHRP2 Renewal solutions are making inroads to advance several areas of transportation practice.

RENEWAL SOLUTIONS 20

230+ PROJECTS IN

STATES 50

STRUCTURES

92% ↓ Reduction in road closure time using *Innovative Bridge Designs for Rapid Renewal* (R04)

Structures including bridges and tunnels are benefiting from SHRP2 Solutions. ***Innovative Bridge Designs for Rapid Renewal* (R04)** has helped agencies achieve a 92% reduction in road closure time on bridge replacement projects. ***Nondestructive Testing for Tunnel Linings* (R06G)** allow the capture of 100 percent coverage of the tunnel walls to improve the safety in tunnels from coast to coast.


PAVEMENTS

32% ↓ Cost reduction for projects using *Composite Pavement Systems* (R21) in Tennessee

Approximately **75 contractors** have invested in technology of *Tools to PCC Pavement Smoothness during Construction* (R06E).

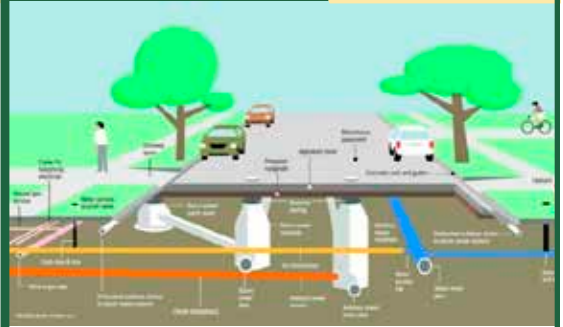
Among the nine SHRP2 pavement solutions is ***Tools to Improve PCC Pavement Smoothness During Construction* (R06E)**, which 10 states have adopted into normal practice to gain higher quality pavements delivered in less time and for less money. In addition, users of ***Composite Pavement Systems* (R21)** have seen a 32% reduction in project and materials costs.

PROJECT DELIVERY

6  Updated their project development manuals and policies based on *Risk Management* (R09) and *Complex Project Management* (R10).

Two key project solutions, ***Managing Risk in Rapid Renewal Projects* (R09)** and ***Project Management Strategies for Complex Projects* (R10)** have been used in the modifications of several state DOT project development manuals, design-build manuals, highway design manuals and other policies and materials, in risk management and project management practices in six states. These updates to project and risk management practices are creating sound decision-making and project management strategies to ensure successful and timely completion.

UTILITIES



4:1 Potential using *Utility Investigation Technologies* (R01B) to avoid utility conflicts.
SAVINGS

Utility-roadway conflicts are a significant source of project cost and delay. This complex challenge is addressed with the SHRP2 ***Utility Bundle* (R01A/R01B/R15B)**. This bundle of three SHRP2 Solutions is being used to help locate utilities, put 3D information into an accessible repository, and effectively manage utility conflicts. Agencies achieve a 4:1 savings by using these solutions on projects.

RAILROAD COORDINATION



SAVED
\$250,000

by Florida using R16 flagging agreements

Texas saw **50% reduction** in approval times using R16

SHRP2 Solutions not only build better roadways, but they also build better partnerships. ***Railroad-DOT Mitigation Strategies* (R16)** improved cooperation between Florida DOT and a railroad to save the agency \$250,000 using R16 flagging agreements.

RENEWAL FEATURE STORIES

Time-saving Utility Solutions Minimize Construction Risks



Our transportation infrastructure serves to connect us to each other in all the most important ways. We use our infrastructure to connect us to our families, our friends, the places where we educate ourselves and our children, and the places we work and play. It's only natural that years ago, when much of our infrastructure was being built, utility lines were run through nearby rights of way to connect communities to basic resources. Now, years later, many roads and bridges have either reached the end of their useful lives or need significant maintenance or improvement. When it comes to designing and implementing transportation projects, potential conflicts with existing utility lines can dramatically impact efficient project delivery.

The importance of utility management during construction made national headlines in 2017, when contractors constructing a replacement bridge in the Outer Banks of North Carolina drove a steel casing into an electrical transmission system, completely cutting off power to the islands of Hatteras and Ocracoke. The outage, which would take a week to fix, resulted in the mandatory evacuation of an estimated 60,000 tourists. County officials estimated that the economic impact to the many small businesses on Hatteras Island alone was in the range of \$2 million per day—about \$13 million in total. There is no way to estimate the cost to the thousands of families who were unable to recoup their losses due to nonrefundable travel fees and vacation rental homes they were not allowed to use.

While there are no reliable statistics on how often utility lines are cut or damaged during construction activity, transportation professionals across the board regard potential utility conflicts as one of the top three factors contributing to construction delay, according to Cesar Quiroga, a SHRP2 subject matter expert.

“Managing utilities when coordinating a transportation construction project is a complex process that poses many challenges,” Quiroga explained. “First, there is a widespread lack of accurate, complete information about utility facilities that might be in conflict with a planned construction project. It is not uncommon for utilities to have inaccurate or incomplete maps of where their active utility lines are located. In addition, sometimes utilities will install an unmapped active line but leave an inactive line in place, leading to confusion, added cost, and delays when contractors dig where they believe it is safe only to damage an active utility line that they did not know was there.”

These challenges have led to the rise in subsurface utility engineering (SUE). The purpose of SUE is to identify the quality of subsurface utility information needed for highway plans and to acquire and manage that level of information during the development of highway projects. In many states, SUE has become a routine requirement for highway projects since one of its functions is to address problems caused by inaccurate utility records, abandoned or unrecorded facilities, and lost references.

To help agencies improve their SUE processes and approaches, and to address the added cost and delays that can result from utility conflicts, SHRP2 developed a series of products — called the **Utility Bundle** — that are assisting agencies both in determining where active utility lines are located and how to work around them.

Finding and Tracking Utility Lines is a First Step in More Comprehensive Coordination

Inadequate utility location data exists throughout the utility industry, which ultimately affects transportation construction projects by causing cost and time overruns. As transportation agencies migrate to 3D technology for design and construction, transportation agencies need a system to store and retrieve utility data to better coordinate and resolve utility conflicts. The utility database technology needs to work with existing agency databases and systems.

In response, SHRP2 developed a 3D storage and retrieval data model through its **3D Utility Location Data Repository (R01A)** solution. The repository is designed to accommodate large volumes of utility data, interface with existing design software, and provide a method for organizing the data so that it can be used reliably throughout both current projects' life cycles as well as for future projects. The data stored include three-dimensional (width, depth, height/length) utility location information, as well as attribute data needed to effectively coordinate with utility owners.

The benefits to having this knowledge are extensive:

- More efficient and productive coordination with utility owners.
- The ability to modify project designs to avoid costly utility relocation and project delivery delays.
- The enabling of contractors to pull up mapping systems that accurately display the location and depth of the utilities during construction so the utilities can be avoided and delays prevented.
- The ability to store data in a single platform, minimizing the cost of data collection on future projects.

The second product in the *Utility Bundle* complements the utility location data repository solution. The **Utility Investigation Technologies (R01B)** product promotes the application of the two utility detection technologies that the initial SHRP research found to be the most advanced: multi-channel ground penetrating radar (MCGPR) and time-domain electromagnetic induction (TDEMI) geophysical imaging tools. These tools can be used to establish the three-dimensional positioning of known and unknown utilities, as well as provide a new format of 3D digital information that can be incorporated directly into design software for excavation

The SHRP2 Utility Bundle (R01A/R01B/R15B) is designed to move away from the current state of the practice where utilities are dealt with during construction and instead address utilities during all phases of project delivery, starting as early as planning and continuing through preliminary engineering, design, and construction. The SHRP2 product approach also addresses the utility process in the post-construction period, offering practices and techniques that can improve utility permitting and data collection and management throughout the life of both transportation and utility facilities.

and construction activities. This digital information is in a format that can be uploaded into an agency's utility location data repository.

The use of MCGPR and TDEMI tools represents a new paradigm for imaging utilities and advancing agencies' SUE practices. The purpose of SUE is to identify the quality of subsurface utility information needed for highway plans and to acquire and manage that information during the development of highway projects. In many states, SUE has become a routine requirement for highway projects—especially since one of its functions is to address problems caused by inaccurate utility records, abandoned or unrecorded facilities, and lost references.

During 2016 and 2017, about 200 individuals from transportation agencies in seven states received hands-on classroom training and field demonstrations for these two highly complex and advanced imaging systems. Post-training feedback reflected that these technologies are much more sophisticated than had been expected, and attendees were glad for the opportunity to learn how they work and, more importantly, how to use them. The consensus among attendees was that they came away with a much deeper understanding of both the limitations and advantages of the two different technologies and how they could be used to enhance SUE programs.

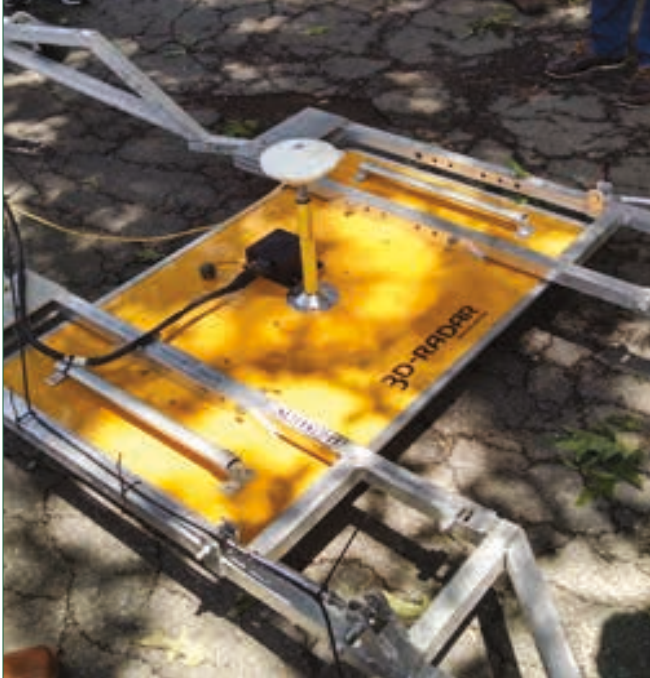


Figure 1: 3D-RADAR DSG (with GPS) MCGPR towed antenna array.

Photo courtesy of Phil Sirles, Olson Engineering

Currently, most states using the product through the SHRP2 IAP are in the planning and solicitation stages of their implementation efforts. One state, Virginia, planned to conduct the first of two projects, deploying both MCGPR and TDEMI, in fall 2017. The other implementation states have expressed eagerness to initiate their projects as well.

“I believe this next phase of project (fieldwork to be performed by the states) will lead to a new acceptance of digital 3D utility imaging and incorporation of these data into design and construction,” said Phil Sirles, a geophysical engineer and subject matter expert supporting the SHRP2 R01B Round 7 implementation. “It will be exciting to witness the state efforts and then report on the results from the R01B technology deployment,” he added.

Avoiding, Minimizing, and Mitigating—It Just Makes Sense

Identifying and locating utility lines is half the battle in addressing utility management during construction. The other half occurs when planners need to decide how to deal with those utilities. Many agencies are realizing the benefits of avoiding, minimizing and mitigating impacts to utilities. If a transportation project’s design can be slightly modified to avoid impacting the utility, then time and money might be saved in the long run.

“Agencies are now realizing that we don’t always need to do relocation if we can modify the project design just a bit,” Quiroga noted, pointing to a 2014 pilot project in Maryland where the alignment of drainage pipes in the proposed construction plan were adjusted to avoid conflicts with existing gas lines. This small change resulted in savings of more than \$500,000 and eliminated 4-6 months of construction delay, he added.

“During the SHRP2 research phase several years ago, the concept of avoiding utilities began to emerge. Eventually, this evolved to avoiding, minimizing, or mitigating—in that order—as we do for the environmental process. Once you’ve exhausted those three strategies, then you have to relocate,” Quiroga explained. This concept for avoiding, minimizing, and mitigating became the foundation for the products developed under the SHRP2 **Identifying and Managing Utility Conflicts (R15B)** effort.

“Ideally, agencies will start coordinating the utility aspect of projects during the planning stage, even before design,” Quiroga concluded. “They should say to the utilities, ‘We’re starting to think about this. You should too.’”

Utility conflict management (UCM) is an overarching concept and set of procedures for identifying and resolving utility conflicts. The UCM process includes proactively identifying both utility conflicts and alternative design solutions that will minimize costs and support better, more efficient communication among transportation project designers and planners, contractors, consultants, and utilities. When implemented, these improvements lead to more cost-effective processes with greatly reduced risk.

The R15B products were designed to address the two critical factors that make managing utility issues during project development and delivery less efficient: the lack of accurate, complete information about utility facilities that might be in conflict and the resolution and overall management of those conflicts. To mitigate both factors, the Texas Department of Transportation (TxDOT), a lead implementer of SHRP2 R15B, is focusing on early coordination and using a standardized approach to developing designs that address utility management.

“The SHRP2 R15 program has helped to transform the way TxDOT manages the utility conflict resolution process in our projects,” said Anna Pulido, P.E., TxDOT utility manager for the San Antonio District. “The new

approach adopted by TxDOT staff, consultants, and utility partners consists of early coordination, extensive communication, and designing to avoid or minimize impacts to our utility partners. This process produces a successful project that stays on schedule with no construction delay claims related to utilities.”

TxDOT is improving and streamlining its approach to many elements of the project development process to eliminate costly delays caused by utility relocation. For example, the state now uses a utility conflict matrix (standardized to meet the needs of TxDOT and the state’s utility partners), along with a utility conflict exhibit to illustrate and locate conflicts. Both are treated as living documents and are updated throughout the project. Texas is also revising its internal processes to identify utility conflicts sooner; for example, it is including proposed underground improvements in the 30 percent design submittal rather than waiting until the 60 percent submittal—a change spearheaded by the agency’s engineering operations and project planning teams to address early utility coordination through revised contract scopes. Further, in addition to holding bi-weekly utility coordination meetings to get updates from utility owners, the agency is establishing utility hand-off meetings, which will occur when projects transition from the design to construction phase in order to bring the personnel in charge of the construction phase up to speed on the status of the utilities management effort.

“One key item we are performing now is coordination with utilities at the schematic phase, far in advance of the plans, specifications, and estimates phase,” Pulido said. “We are accommodating utilities by reviewing typical sections that depict utilities—for example, if we’re acquiring right of way, we’re asking ourselves, ‘Can we accommodate the utilities per the utility accommodation rules along with making all the other proposed improvements, like drainage and retaining walls? Can we acquire a few more feet of right of way, or only acquire property on the other side of

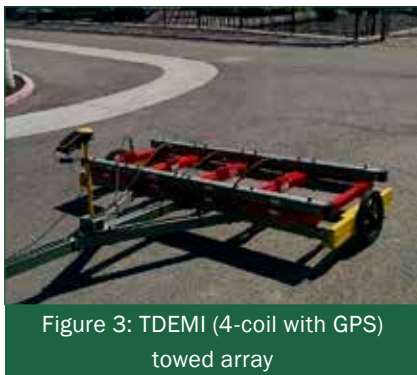


Figure 3: TDEMI (4-coil with GPS) towed array

Photo courtesy of Phil Sirles, Olson Engineering



Figure 2: IDS Stream-EM (with GPS) MCGPR towed antenna array

Photo courtesy of Phil Sirles, Olson Engineering

the highway and avoid utilities altogether?’ All of this planning is occurring at the schematic phase instead of waiting until the plans, specifications, and estimates phase.”

Pulido points to the SHRP2 UCM training as an important introduction to several fundamental aspects of effective utilities management, including the importance of early conflict identification and coordination with utilities, the use of utility conflict lists, and the fact that communication is critical.

“It’s time consuming and expensive to move utilities,” noted Pulido, who was once responsible for managing overhead electric and gas relocations for a Texas energy provider, so utilities in Texas are reacting positively to the DOT’s efforts to communicate and coordinate earlier. “The utilities are responding because they realize we’re engaging them early and demonstrating to them that we are taking utilities seriously. Coordinating early and focusing on avoiding, minimizing, and mitigating just makes sense,” she added.

At present, TxDOT is implementing the SHRP2 R15B product on the \$182 million U.S. Route 281 Phase 2 improvement project, among others. Using the R15B product has already benefitted TxDOT by helping the agency avoid relocating a transmission water line: by shifting the frontage roads along the project approximately five feet closer to the centerline, the DOT determined it would be able to avoid relocating nearly a mile of 24-inch transmission water line. That translates into a savings of about \$1.5 million.

Advanced Pavement Technologies Give Agencies More Effective Tools for Renewing Roadways



In 2013, the latest year for which the FHWA released data, state transportation agencies spent a total of \$110.7 billion on highway capital improvements, including \$30.1 billion in federal funds, on projects to improve 65,500 miles of highway. Another \$25.6 billion was spent on preservation construction, such as roadway resurfacing and bridge repairs. While much needed, these maintenance and improvement projects translate into thousands of work zones across the country each year, which in turn cause up to a quarter of non-recurring freeway delays (traffic incidents and weather are other causes of non-recurring delay). Work zone delay is equivalent to about 888 million hours that Americans spend in congested traffic. Work zones were also the site of 96,626 crashes in 2015, making them some of the most dangerous places to work or travel through.

Rapid construction methods are important, not only because they can produce more durable, long-lasting pavements and bridges, but also because they can significantly minimize traffic congestion and reduce risks to road users and builders. Many of the advances in pavement and bridge technology have the added benefit of significantly increasing the life span of a roadway—up to 50 years. To make it easier for road owners to adopt advanced pavement technologies, SHRP2 developed a series of tools to help agencies learn how to integrate these advanced products into their pavement rehabilitation toolboxes. To date, the results have shown that implementing agencies are realizing safety and mobility benefits, reducing maintenance costs, and improving their processes for building or reconstructing roadways. These tools have been developed so road builders can get in, get out, and stay out, giving our customers greater access to the nation's highway system.

Precast Concrete Pavements Speed Reconstruction on High-Volume Roadways

The **Precast Concrete Pavements (R05)** product – a modular pavement technology – is one such tool. It addresses the challenge of maintaining quality pavement on heavily-traveled urban streets and arterials, often over multiple utility lines. During the past decade, many transportation agencies have discovered that using modular, precast concrete pavement (PCP) systems on such critical, high-volume roadways can speed repairs or reconstruction. One of the greatest benefits of modular pavement technology is that it shortens construction time, particularly on projects where detours are not feasible. For instance, busy intersections can be constructed in phases and at night, allowing the full intersection to be open to traffic each morning and afternoon during peak traffic periods. This technology can also be used on small road segments such as concrete panel replacement projects, enabling flexibility in construction timing. It can also be used on corridor-wide pavement rehabilitation projects.

SHRP2 investigated 16 PCP projects at locations with a wide range of climates (from colder, wetter northern states to hotter, drier southern states) and assessed how the PCP systems were used in areas such as ramps, toll plazas, at-grade roadways, and airports. The research found that well-designed and well-constructed PCP systems can provide high-quality, long-term service and are often a good choice for rapid repair and rehabilitation of existing pavements. To date,



Photo: courtesy of 2017 Google, Map data.

Figure 1: Aerial view of ALDOT Exit Ramp from South-Bound I-165

dozens of projects have been constructed, and advances continue to be made in all aspects of the technology, including panel design, fabrication, and installation. PCP is a flexible tool, and can be used in a variety of ways to speed project delivery.

In Hawaii, for example, the Hawaii Department of Transportation implemented a project using PCP to replace a section of concrete pavement that had been overlaid with progressively thicker layers of asphalt over a 20-year period to address road settlement issues. The project on Interstate H-1 on the island of Oahu required placement of 70 panels across five lanes of the busiest road on the island. Over half of Oahu's population depends on this corridor for daily travel. To minimize work zone impacts, work was performed during a series of daily work zones maintained from noon until 6:00 the following morning.

According to Gary Iwamoto, director of construction services for the design consultant on the project, "PCP offered significant advantages to the project within our urban core where detour routes were not available or were impractical. We have found that the overnight repairs are very reliable and could be accomplished in weather conditions where asphalt or poured-in-place concrete could not be used."

The Illinois Tollway also used PCP for the replacement of bridge approaches where embankments have settled and damaged approach slabs needed to be replaced quickly to minimize traffic delays. During 2015, the Tollway developed a precast panel system for rehabilitation of bridge approach slabs using 30-ft-long and 12-ft-wide (nominally) structurally reinforced panels. This system was used for the rehabilitation of the approach slabs to the Midlothian Turnpike Bridge along I-294 in June 2015. The Tollway also has plans to investigate the possibility of using PCP in the construction of approaches for new bridges because the increased durability of the product may help eliminate the stress cracks that develop on cast-in-place panels.

"PCP approaches will be constructed as part of several expressway integral abutment bridges being built for the Tollway's new Elgin-O'Hare corridor, and hopefully for many more in the future as the Tollway's expansion and reconstruction program continues," according to Steven Gillen, deputy program manager for the Illinois Tollway.

The Kansas Department of Transportation (KDOT) is using PCP to rehabilitate several intersections along a section of US 73 that serves through-traffic, as well as traffic entering and leaving Fort Leavenworth. This project included subgrade remediation work and new

base placement. KDOT also is considering using PCP more widely, such as for replacing bridge approaches and for implementing rapid full-depth repair and rehabilitation of pavements.

Will Lindquist, concrete research engineer at KDOT said, "Precast concrete panels were selected for their potential to provide long-term durability and because they can be installed quickly, helping to minimize disruptions in the busy intersections and bridge approach. The panels offered an alternative to high-early strength cast-in-place concrete with the advantage of being produced in a controlled environment at a PCI certified plant without concern for concrete maturity."

The Alabama Department of Transportation (ALDOT) recently replaced two left-turn lanes of the Exit 2 ramp from southbound I-165 in the Mobile area with precast concrete panels. This exit carries a high volume of heavy truck traffic into the Port of Mobile. Traffic from I-165 decelerates on this downhill ramp and frequently comes to a complete stop at the signalized intersection at the end of the ramp. The existing pavement on this ramp consisted of eight inches of asphalt on an aggregate base. Rutting and shoving of the asphalt required repeated maintenance.

A complete shutdown of these two ramp lanes for an extended period was not feasible, so the contractor was limited to a work window from 8:00 p.m. to 6:00 a.m. the following morning. Construction started with the trial installations of four panels, and was completed on subsequent nights with up to fourteen panels installed



Figure 2(a): Typical rutting of existing asphalt.

in a single night. An aerial view of this two-lane ramp is shown in Figure 1. Project features are shown in Figure 2: (a) typical rutting of existing asphalt, (b) placement of a pre-tensioned two-lane width panel (four leveling lifts are included in each panel as fabricated at the precast plant), and (c) the completed roadway following under-panel grouting.

Precast concrete was chosen by ALDOT for this project to provide a maintenance-free long-life pavement that could be constructed in strictly enforced overnight work windows. This project qualified for IAP assistance because similar needs exist throughout the country for reconstruction of both asphalt and concrete ramps, intersections, bridge approaches, underpasses and bus pads. ALDOT is considering the implementation of PCP on a state-wide basis for similar applications.

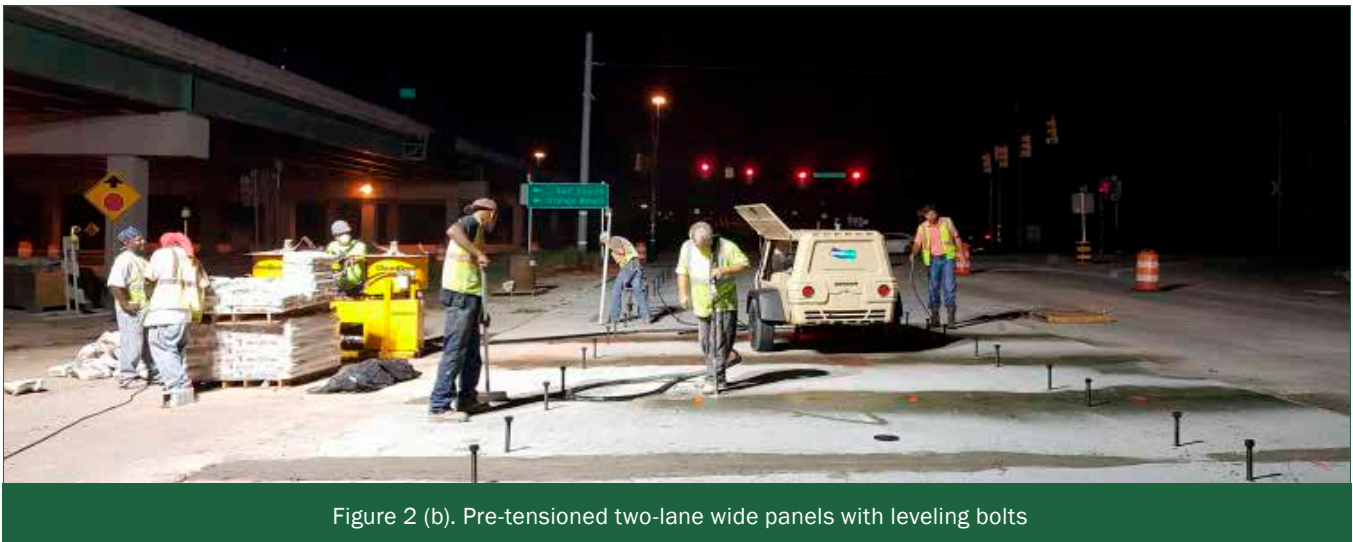


Figure 2 (b). Pre-tensioned two-lane wide panels with leveling bolts

SHRP2 *rePave* Tool Expands Strategy Options for Rapid Renewal Projects

If a pavement section reaches a point where preservation is no longer cost effective, rehabilitation will be required to restore its structural capacity. SHRP2 recognizes that employing a rehabilitation strategy that takes advantage of the remaining structure in the existing pavement can accelerate the project and reduce costs. To achieve long life under conditions of service likely not considered in the original design, however, requires agencies to select the appropriate solution for specific circumstances. In response, **Pavement Renewal Solutions (R23)** produced a web-based scoping tool called *rePave* that assists pavement designers and project engineers in selecting optimal long-life pavement rehabilitation strategies when scoping planned projects for the future.

The *rePave* decision-support tool offers rehabilitation strategies that are applicable for rehabilitating existing flexible, rigid, and composite pavement structures with the goal of identifying renewal strategies for pavements that will have service lives in the range of 30 to 50 years. The main focus of the rehabilitation strategies proposed by the *rePave* tool is on reusing elements of the existing roadway, meaning leaving some part of an existing roadway in place and incorporating it into the new pavement structure. This tool broadens the remediation strategies available to planners and designers, conserves resources by requiring less new pavement, and helps agencies garner cost savings from more durable roads that need less maintenance and have a longer life span.

Imad Basheer, Ph.D., P.E., a senior pavement engineer who is leading the effort to incorporate the use of *rePave* into the project scoping process for pavement-in-place projects at the California Department of Transportation, noted that environmentally friendly technologies that emphasize the reuse of materials are on the rise, so the R23 product is very timely because it provides a larger set of strategies to choose from while allowing the engineer to recycle as much as possible given the needs of the project.



Figure 2 (c). Precast Left-turn lanes open to traffic

Looking for a long-lived, cost-effective solution, Washington State Department of Transportation (WSDOT) volunteered to pilot an early version of the *rePave* product for a rehabilitation project on I-5. By identifying additional pavement rehabilitation alternatives through the *rePave* decision-support tool, WSDOT was able to achieve significant savings initially and projected out over the pavement's life cycle. WSDOT calculated that the strategy it selected saved 19 percent in initial agency costs, 16 percent in agency costs for the roadway life span, and 28 percent in user costs over the life span. In addition, construction-required lane closures were reduced by 43 percent.

The strategies identified by the *rePave* tool are based on characteristics such as existing distress conditions and other general project and design details. Other required inputs include basic data such as expected life, structure, material types and thicknesses, surface condition, subgrade type, and vertical grade controls—all of which are commonly available to the project engineer at an early stage, making *rePave* a helpful tool for any state's rehabilitation program.

“One of the most beneficial aspects of using the *rePave* scoping tool is to provide project engineers at the scoping phase a wider set of strategies that incorporate recycled materials into long-life pavement projects,” Basheer said. “This can help the pavement designers select the best and most cost-effective strategy for their projects, which can potentially save taxpayer dollars, reduce the occurrence of traffic interruption due to frequent rehabilitation needs, and reduce the negative impact on the environment.”

Better Pavement Preservation Practices Reduce Risk, Improve Performance

States use a variety of pavement preservation techniques to protect and maintain existing pavements and increase their projected life span. These techniques include applying seals, micro-surfacing processes, overlays, and crack fillers. Indeed, many transportation agencies have a toolbox of preferred pavement preservation techniques that they commonly apply to successfully extend service life and improve ride quality on lower volume roadways, often at a lower cost than resurfacing.

However, many of the products and approaches that have been used on lower-volume roadways have not been widely accepted for use on high-volume roadways, even though they may provide valuable preservation benefits. Often, agencies perceive that the use of a particular product or application has too great an impact on traffic, or it is not aware that a treatment has been successfully applied in other states under high-traffic conditions. Some states have concerns about lack of durability due to the high volume of traffic on the roadway, or the cost-effectiveness of applying a treatment that may have to be re-applied more frequently than anticipated.

Transportation agencies are inherently risk averse, noted Dave Peshkin, P.E., a subject matter expert in pavement maintenance and rehabilitation who is supporting the SHRP2 **Guidelines for the Preservation of High-Traffic-Volume Roadways (R26)** implementation effort. “That is something that is very important to highway agencies, knowing there are others with experience, that the techniques have been used successfully, and finding out about those experiences so they're not taking as great a risk as they thought they had. They can look at what others had done and learn from it,” Peshkin said.

To overcome these challenges and misperceptions, SHRP2 developed **Guidelines for the Preservation of High-Traffic-Volume Roadways**. Based on a comprehensive survey of 40 state highway agencies, seven Canadian provinces, and three cities, as well as a review of existing successful preservation techniques, the SHRP2 R26 Guidelines were designed to include techniques that are commonly used to preserve

low-volume roadways but that have also been used successfully on a broader range of road types, including high-volume roadways. The R26 Guidelines also provide a systematic approach that takes into account a variety of road conditions and proper timing of treatments to reduce negative traffic impacts and ensure that the preservation solution they choose will be effective on the facilities where it is applied, regardless of volume.

The Guidelines increase the range of solutions transportation agencies have to choose from—as well as their confidence in those solutions—when considering their pavement preservation options. It does this by presenting a portfolio of vital information on more than 20 treatments that have proven cost effective, allowing the user to account for diverse environmental and traffic conditions, and providing selection matrices to help match specific high-volume-traffic situations with the best available treatments.

One example of a state that has had notable success with the R26 Guidelines is Kentucky. Due to rising asphalt prices, the Kentucky Transportation Cabinet (KYTC) is using the guidelines to broaden use of pavement preservation, keep good roads in good condition longer, and apply low-cost preservation solutions on more miles of roadway, maximizing the resources available for road rehabilitation activities.

Although internal guidelines for pavement preservation treatment applications had been developed and used by KYTC prior to the SHRP2 R26 implementation, the IAP efforts reinforced the Guidelines' value based on credible experience from several states, including Kentucky. The agency found that alternative treatments were used in other states to lower life-cycle costs, and their functionality in Kentucky is reported to be similar. Using the guidelines, KYTC has applied multiple treatments on a four-lane rural arterial with average daily traffic of 12,800 vehicles. KYTC officials indicated that its experience in using the guidelines has motivated the agency to move toward newer approaches to extending the life of roads.

Since the IAP, KYTC has developed thresholds for treatment selection that complement the Guidelines and fit with the KYTC pavement rating process. Using more consistent pavement evaluation and treatment selection practices has made it possible for the agency to move from applying alternative treatments on an occasional basis to an approach that involves the systematic application of 300 lane miles of alternative treatments in 2016. In effect, Kentucky has adopted the R26 Guidelines into its internal preservation policy, and their use continues to grow in what can now be considered the “new normal.”

Using the guidelines, KYTC has applied multiple treatments on a four-lane rural arterial with average daily traffic of 12,800 vehicles.



CAPACITY

Bringing greater collaboration to transportation decision making



SHRP2 Capacity Solutions

- **PlanWorks (C01)**
- **EconWorks (C03/C11)**
- **Implementing Eco-Logical (C06)**
- **Planning Process Bundle (C02/C08/C09/C12/C15)**
- **TravelWorks (C10/C04/C05/C16)**
- **Expediting Project Delivery (C19)**
- **Freight Demand Modeling and Data Improvement (C20)**

The SHRP2 Capacity focus area's charge from Congress was to “develop approaches and tools for systematically integrating environmental, economic, and community requirements into the analysis, planning, and design of new highway capacity.”

The resulting research developed several solutions to help agencies at the state and local levels systematically apply knowledge in these areas to increase the probability of success and the timely delivery of projects. The set of Capacity solutions are particularly effective due to their applicability throughout the project delivery process.

The keys to success in planning and obtaining approvals for complex transportation projects include:

- Collaboration among stakeholders,
- Better modeling and economic analysis tools,
- Consideration of environmental needs, and
- Enhanced performance measures.

Our nation's roadways are an important part of our communities as they connect people and support commerce. Because of the crucial roles roadways play, transportation agencies should be stewards of environmental and community concerns while delivering transportation projects in ways that support each community's vision.



SHRP2 Capacity Solutions

The SHRP2 Solutions developed from the Capacity focus area research provide practical tools, technologies, and strategies for each phase of the project delivery process. The goal is to plan and design a highway system that offers minimal disruption to and meets the environmental and economic needs of the community.

COLLABORATION



- ▶ Twelve state DOTs and MPOs have used **PlanWorks** to engage cross-disciplinary partners and stakeholder groups throughout the transportation planning, programming, and project development processes.
- ▶ Virginia DOT applied **PlanWorks** to collaboratively develop and build consensus for a \$19.43 million set of corridor preservation and access management projects for the Route 29 Corridor.

FORECASTING



- ▶ Integrate activity-based modeling and dynamic traffic assignment.
- ▶ Improved practical decision-making capabilities.
- ▶ Piloted and evaluated the technology readiness of advanced models.
- ▶ Developing demonstration and training sets.

ECONOMIC ANALYSIS



- ▶ Added more case studies to increase the relevance to state DOTs and MPOs.
- ▶ Improved familiarity with wider economic benefits of reliability.
- ▶ AASHTO will continue to support **EconWorks**.

PERFORMANCE MEASURES



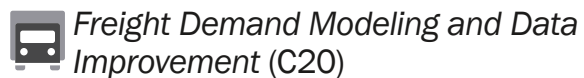
- ▶ Used by seven state DOTs and MPOs to develop program-level, plan-level, and project-level performance measures and to garner stakeholder input and buy-in regarding performance-based planning and programming.
- ▶ The Atlanta Regional Commission used C02 to expand the list of performance factors used in transportation decision making during long-range planning.

PROJECT DELIVERY



- ▶ Identified 26 strategies to address project constraints.
- ▶ Florida DOT saw a reduction of up to one year for categorical exclusion projects.
- ▶ Vermont Agency of Transportation has realized a 35 percent savings in average preliminary engineering costs for 30 bridges.

FREIGHT



- ▶ Developed innovations in freight data and modeling to more fully integrate freight into the transportation planning process.
- ▶ Assisted in development of four behavior-based freight models to better replicate economic behaviors of industry supply chains, freight flows, distribution of goods, and truck tours in Arizona, Maryland, Oregon, and Wisconsin.

ENVIRONMENT



- ▶ Level of familiarity with Eco-Logical particularly among state DOTs, is up to 80 percent.
- ▶ MPOs are increasingly using Eco-Logical to integrate ecosystem considerations into transportation planning.

CAPACITY FEATURE STORIES

Applying the Eco-Logical Approach to Transportation Project Development



Eco-Logical is a landscape-scale approach to transportation project development that has seen widespread adoption across the nation. This has resulted in benefits to environmental resources, accelerated transportation project delivery, and reduced costs. The SHRP2 IAP helped to fund 13 state DOTs and Metropolitan Planning Organizations (MPOs) and establish Eco-Logical as a standard business practice in many agencies. Through four years of SHRP2 implementation (2012-2016), the number of practitioner agencies has increased by approximately 40 percent. The level of familiarity with Eco-Logical — particularly among state DOTs — is approximately 80 percent, while MPOs are increasingly using Eco-Logical in their regions for project selection and delivery.

Under SHRP2 implementation, the number and quality of technical assistance resources have increased, with FHWA and AASHTO delivering peer exchanges, workshops, trainings and webinars on a wide range of topics relevant to Eco-Logical practitioners. Eco-Logical is also being encouraged on a national scale. Since 2012, at least seven new regulations, policies, and executive actions — including the Fixing America's Surface Transportation (FAST) Act — have shown a major shift towards adopting landscape-scale approaches to conservation planning and infrastructure development.

The Vision: Encourage Use of a Landscape-scale Approach to Project Development

Implementing Eco-Logical (C06), as part of SHRP2, is focused on:

- Widespread use of integrated highway and conservation planning and development strategies.
- Expediting environmental reviews and permitting.
- More effective environmental mitigation, producing predictable and sustainable conservation.
- Improved public perception of transportation delivery services.

A major goal of Implementing Eco-Logical is to achieve widespread use of the Eco-Logical approach within 10 years. FHWA developed the Integrated Eco-Logical Framework (IEF) to assist agencies with adoption of a landscape-scale approach —from early collaboration with resource and regulatory agencies through development of formal mitigation agreements and crediting systems.







The IEF provides a step-wise process that guides transportation agencies to form strong partnerships with resource and regulatory agencies, incorporate natural resource data into planning and decision making, and establish joint priorities to avoid critical environmental resources while meeting key infrastructure objectives. For more information on Implementing Eco-Logical and its nine steps, please visit: <https://www.environment.fhwa.dot.gov/ecological/ImplementingEcoLogicalApproach/>.

Making that Vision a Reality

The FHWA and AASHTO developed six strategies to promote the adoption of *Implementing Eco-Logical* as part of routine business practices at state DOTs, MPOs, and federal and state resource and regulatory agencies.

1. **Educate agency leadership** – Identify and equip champions of the Eco-Logical approach, offer executive training, and develop a Practitioner’s Handbook.
2. **Develop incentives and support** – Provide incentive grants and assistance for implementation and organize awards and other recognition for practitioners.
3. **Provide technical assistance** – Develop technical assistance teams, sponsor peer exchanges and forums, and develop a “starter kit” website for Implementing Eco-Logical.
4. **Develop a business case** – Develop case studies, quantify lifecycle costs and benefits, and conduct targeted outreach to stakeholders.
5. **Develop new tools and technologies** – Facilitate data management and access and develop structures to foster collaboration among agencies implementing Eco-Logical.
6. **Develop communications and outreach materials** – Develop and implement a strategic marketing and communications plan and on create an informational video.

These six strategies have been used by FHWA and AASHTO to track performance of the *Implementing Eco-Logical* program and communicate the benefits of Eco-Logical to leadership.

Implementation Strategies	Accomplishments
 Educate agency leadership	<ul style="list-style-type: none"> ● 56 Champions nationwide ● 2 Executive Training Sessions ● Practitioner’s Handbook produced ● 2014 & 2016 assessments conducted
 Develop incentives + support	<ul style="list-style-type: none"> ● Approx. \$1.9 million provided to 13 State DOTs and MPOs ● 14 projects completed ● Letters of recognition provided
 Provide technical assistance	<ul style="list-style-type: none"> ● 10 peer exchanges and workshops ● Web-based, on-call technical assistance request form launched ● Starter Kit website released
 Develop a business case	<ul style="list-style-type: none"> ● 4 case studies highlighting the 9 IEF steps produced ● Business case demonstrating cost and time savings of Eco-Logical developed
 Develop new tools + technologies	<ul style="list-style-type: none"> ● 4 Community of Practice webinars held ● Integration of SHRP2 PlanWorks with Implementing Eco-Logical commenced
 Develop communications + outreach materials	<ul style="list-style-type: none"> ● Strategic marketing and communications plan prepared and implemented ● Informational video celebrating 10-year anniversary of Eco-Logical produced

Building the Business Case

The key to successful widespread adoption of Eco-Logical was providing monetary incentives. The Michigan and Maine departments of transportation each received \$250,000 in SHRP2 Implementation Assistance (plus supporting technical assistance) to integrate the Eco-Logical approach into their transportation planning and project delivery processes. These two agencies implemented nearly all nine Eco-Logical steps, from strengthening partnerships to creating a Regional Ecosystem Framework (REF) to developing formal programmatic agreements. Their stories are described below.

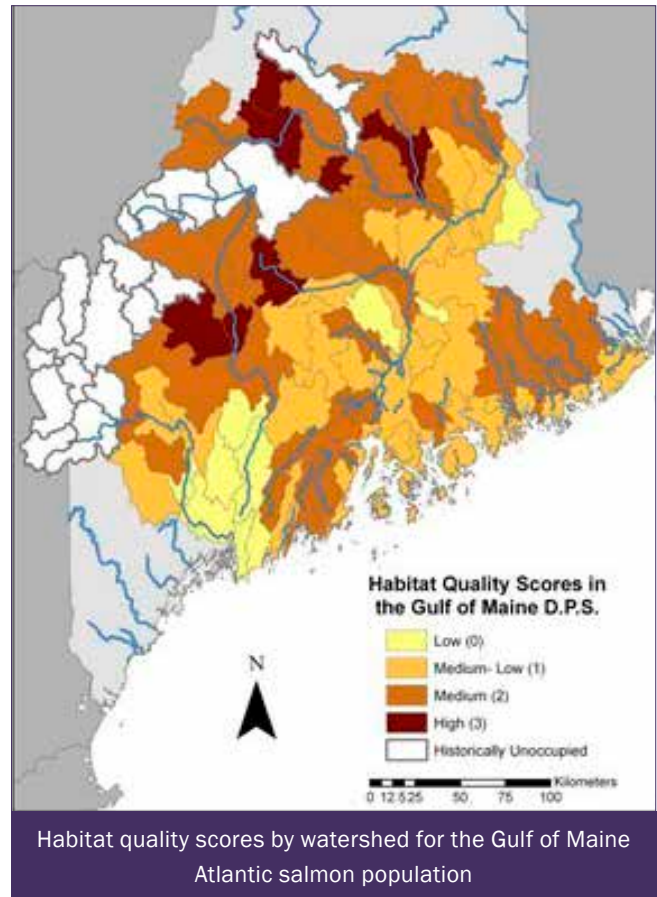
MaineDOT Atlantic Salmon Programmatic Consultation & In-lieu Fee Program

The FHWA and Maine Department of Transportation (MaineDOT) developed a programmatic Endangered Species Act consultation and in-lieu fee program (ILF) for the federally listed endangered Atlantic salmon, which incorporated concepts from the Eco-Logical approach. This effort took four years to complete at an approximate cost of \$276,000, of which \$250,000 was provided through a SHRP2 *Implementing Eco-Logical* IAP award.

Working closely with FHWA and the U.S. Fish and Wildlife Service (USFWS), MaineDOT completed the Atlantic Salmon Programmatic consultation in 2017. The consultation covers a range of transportation projects likely to result in unavoidable adverse impacts to Atlantic salmon and their critical habitat. MaineDOT also created an Atlantic salmon-specific ILF program in partnership with the U.S. Army Corps of Engineers. The program will allow public agencies, non-profit organizations, and private individuals to apply to use funds for restoration, enhancement, and preservation projects.

Since 2013, collaboration and formal agreements and consultations among MaineDOT, FHWA, USFWS, U.S. Army Corps of Engineers, and other partners have resulted in a number of key accomplishments and benefits:

- Full implementation of the Programmatic Biological Opinion and ILF program in 2018.
- Increased collaboration with partners and less conflict on Endangered Species Act-related issues.
- Expected coverage for approximately 60 projects annually (75 percent of projects requiring consultation), compared to seven projects annually in prior years.
- Anticipated doubling in the number of large culvert replacement projects and substantial increase in the number of bridge replacement projects delivered annually.
- Expected annual direct cost savings of over \$150,000 for MaineDOT from use of a streamlined project notification process in place of individual assessments.
- Decrease in USFWS consultation timeframes for MaineDOT projects requiring section 7 formal consultation from eight months to one, reducing the consultation backlog for USFWS.
- Increased consistency of mitigation efforts through the ILF program, in line with Atlantic salmon restoration goals.
- Substantially improved conservation outcomes for the Gulf of Maine Atlantic salmon population.



MaineDOT's use of the Eco-Logical approach demonstrates the benefits of the programmatic mitigation aspects of Eco-Logical in particular. The Atlantic salmon consultation and ILF program have brought significant benefits to MaineDOT and its partners, in terms of flexibility, cost savings, and better outcomes for the species.

Michigan Department of Transportation and I-75 Corridor Project

In Michigan's case, the Michigan Department of Transportation (MDOT) applied the Eco-Logical approach in the Interstate 75 (I-75) corridor in southeast Michigan. SHRP2 funding supported the development and implementation of MDOT's REF and Conservation Action Plan facilitating the reconstruction of the I-75 corridor in five phases, the first of which was completed in 2016.

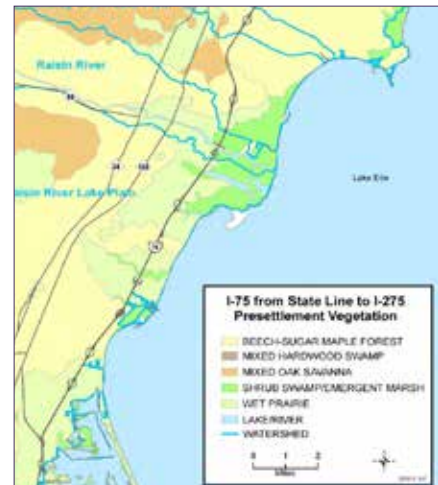
As part of this effort, MDOT created a Technical Advisory Committee of state and federal resource, regulatory, and planning agencies to help create an REF and Conservation Act Plan. MDOT experienced a high degree of engagement from its partner agencies in the Technical Advisory Committee, particularly in deciding on geographic study areas in the I-75 corridor, and in selecting nine conservation targets (e.g., water quality, fisheries, and coastal wetlands).

These agencies are helping to identify mitigation opportunities for MDOT's upcoming reconstruction and renovation work in the I-75

corridor in the short term and over the next two decades.

Since 2013, MDOT has realized a number of benefits through use of Eco-Logical:

- Strengthened partnerships and coordination with natural resource agencies, through data sharing and land use agreements.
- Savings of over \$1,000,000 in the first phase of the project, largely due to reduced land acquisition costs.
- Reduction in permitting timeframes.
- Creation of a framework for landscape-scale project planning that is expected to carry over to related highway reconstruction projects statewide.
- Enhanced environmental outcomes for wetlands and threatened and endangered species.
- Ability to leverage relationships with resource and regulatory agencies to promote conservation activities outside of roadway corridors.
- Improved consideration of the human element of conservation efforts.



Conservation planning maps used to create MDOT's REF

The partnerships established via this project helped MDOT gain consensus among stakeholders and effectively use land resources and data sets managed by other agencies. As a result, MDOT has been able to establish a framework for enhanced environmental outcomes in concert with cost and time savings for highway projects.

Eco-Logical: Environmental Streamlining at its Best

Agencies considering applying the Eco-Logical approach should feel confident they will get added value from considering infrastructure development on an ecosystem-scale. The six strategies for implementation, from educating agency leadership to creating a business case, have helped bolster understanding and accelerate adoption of Eco-Logical across the country.

Maine and Michigan's Eco-Logical approaches are examples of environmental streamlining at its best. Those and other efforts across the

country continue to show that the Eco-Logical approach can make project development and delivery more efficient and improve resource conservation — one of the primary objectives of the SHRP2 program. Identifying and engaging partners early in the project planning process helps to reduce conflicts and results in significant resource, time, and cost savings. Formal agreements with resource and regulatory agencies and mitigation programs can greatly accelerate project delivery.

Past experience has shown it takes up to 10 years for agencies to fully integrate a landscape-scale approach such as Eco-Logical into their everyday business practices. FHWA and AASHTO continue to work to increase adoption of landscape-scale planning across the country by offering training, workshops, and targeted technical assistance to state DOTs and MPOs. The expectation is that landscape-scale approaches to infrastructure development will soon become business as usual for federal, state, and local agencies across the country.

PlanWorks: Better planning. Better projects.



PlanWorks: Better planning. Better projects. (C01) is a web resource that supports collaborative decision making in transportation planning and project development. *PlanWorks* is built around key decision points in long-range planning, programming, corridor planning, and environmental review. *PlanWorks* suggests when and how to engage cross-disciplinary partners and stakeholder groups. This system can help build consensus throughout these processes. It helps identify barriers to successful project and plan development – and strategies for overcoming them. The four main elements of *PlanWorks* are:

1. **Decision Guide** – A troubleshooting guide describing the common decision points and opportunities for cooperation in the transportation planning and environmental review process. For each of the key decision points, *PlanWorks* provides policy and stakeholder questions, data needs, case studies and examples, and links to tools that can help support the decision.
2. **Assessments** – Interactive assessment tools that enable project stakeholders to identify opportunities to work together, improve interagency cooperation, and expedite project delivery. Assessments can be taken online or downloaded and used offline collaboratively.
3. **Applications** – A series of special topics to be considered in the collaborative decision-making framework, including performance measures, visioning, freight, and many other emerging and complex topics.
4. **Library** – A resource library containing relevant case studies and reports of successful interagency cooperation in the transportation planning and environmental review process.

PlanWorks is the centerpiece of the SHRP2 Capacity research focus area. It incorporates several other SHRP2 products, including ***Implementing Eco-Logical (C06), Expediting Project Delivery (C19), Visioning and Transportation (C08), Public-Private Partnerships (C12), Performance Measures (C02), Freight (C15)***. Originally piloted in 2010, this web resource was tested by transportation agencies and revised based on the results. Using stakeholder and user feedback, FHWA worked with AASHTO and TRB to rebrand the content and organize it in a way that was more user-friendly, resulting in the current *PlanWorks*. This group of stakeholders, known as the Expert Task Group (ETG), continues to provide support on how to best implement *PlanWorks*. ETG also offers advice on how to best provide technical assistance to users.

SHRP2 IAP Encourages Early Adoption of *PlanWorks*

Resources and technical assistance were offered in Rounds 6 and 7 of the SHRP2 IAP to state and local transportation planning agencies interested in using *PlanWorks* to improve collaboration within their transportation planning processes. In total, 12 agencies were given financial and technical support to implement the four main elements of *PlanWorks*, from the Decision Guide to the Library.

The Virginia Department of Transportation (VDOT) received funding as a Lead Adopter to apply the *PlanWorks* Decision Guide to improve their corridor planning process. The project team at VDOT applied the Corridor Planning phase of the Decision Guide to develop corridor preservation and access management projects that can be funded through a variety of mechanisms. The project culminated in a \$19.43 million set of improvements for the Route 29 Corridor, a major highway that serves both statewide mobility and local economic development needs. The team worked step by step through the *PlanWorks* Corridor Planning key decision steps, focusing on COR-2, COR-3, COR-5, COR-7, and COR-9. The built-in collaboration of *PlanWorks* fundamentally drove the project in a variety of ways. First, rather than forming a small technical advisory group, all interested individuals were invited to contribute solutions. One-on-one interviews were also held with key stakeholders. Second, consensus was gathered among stakeholders on deficiencies in the corridor. Third, stakeholders themselves identified solutions in public meetings. Finally, the projects were prioritized by all decision-making partners, including VDOT, the local metropolitan planning organization, and the county.

In addition to the Decision Guide, VDOT also made use of the case studies and resources available in *PlanWork's* Library. Using these resources, VDOT was able to see how other agencies have successfully balanced the trade-offs associated with access management standards. This information led VDOT to provide two sets of performance measures: one for through delay in the corridor and the other for access delay, balancing mobility and local access.

The Strafford Regional Planning Commission/Strafford Metropolitan Planning Organization (SRPC/SMPO) in

Rochester, NH used *PlanWork's* Partner and Stakeholder Assessments to identify strengths and weaknesses in their planning processes. Members of their project workgroup and SRPC/SMPO staff have taken the Partner Assessment three times and seen improvements across the board for all categories. The results of the Partner Assessment show improvements in seven categories: organizational support, tools and technology, decision-making authority, participant stability, role clarity, shared goals, and practitioner communication. After each assessment, the group developed strategies to improve on the five weakest *PlanWorks* categories. To remedy the areas with low scores in the Stakeholder Engagement Assessment, the group created a stakeholder action plan and a communication action plan.

Using *PlanWorks* the North Central Texas Council of Government (NCTCOG) has been able to enhance collaboration with non-traditional partners, focus on innovative planning, and create a foundation for accelerated project delivery. Specifically, NCTCOG used the Visioning in Transportation and the Performance Measures applications to introduce scenarios into their long-range planning process and to use performance measures and targets to inform project decisions. Valuable information was gathered using the Visioning in Transportation application on areas such as technologies, behavior, and travel patterns that will allow NCTCOG to better plan and prepare for a changing future. Through the use of the Performance Measures application, NCTCOG was able to engage with internal and external stakeholders to establish performance measures that go above and beyond the requirements of MAP-21 and the FAST Act.

In addition to the IAP recipients mentioned above, other state and regional transportation agencies are implementing the various components of *PlanWorks* to support outreach efforts associated with statewide Long-Range Transportation plans, improve collaboration in corridor planning, evaluate ongoing collaboration, enhance stakeholder engagement, and establish shared visions among partners. Regardless of the particular component of *PlanWorks* being implemented, these agencies are proving that the use of *PlanWorks* can lead to better planning and better projects.

PlanWorks Continues to Adapt to Meet the Future Needs of Practitioners

As the needs of transportation practitioners continue to change, FHWA continues to update and adapt *PlanWorks* to remain relevant and useful. An updated website, newly developed marketing and outreach materials, and a series of peer exchanges and workshops will soon enhance *PlanWorks*' presence and relevance. As the first major update in several years, the content on the *PlanWorks* website will be refreshed by removing outdated items, as well as identifying new content that reflects the latest thinking on individual topics. FHWA has relied upon the *PlanWorks* ETG to provide vital input on these content changes. The updates will reinforce that *PlanWorks* is a resource for collaboration during all phases of transportation decision making.

Additionally, in the winter and spring of 2018, FHWA will host a series of workshops and peer exchanges designed to increase the visibility and credibility of *PlanWorks* as a resource, both generally and for each phase of the transportation decision-making process. Workshop topics will include Corridor Planning, NEPA and Human Environment, Planning and Environmental Linkages, Long Range Planning and Health, and Performance Based Planning and Programming. Apart from the peer exchanges and workshops, new marketing and outreach materials are being developed, which include training videos, brochures, and updated case studies.

TravelWorks: Better Modeling for More Accurate Planning Decisions

Planners often have difficulty forecasting how highway congestion, congestion pricing, and smart growth policies will affect travel demand. ***TravelWorks (C10/C04/C05/C16)***, is a set of advanced travel analysis tools that address today's transportation planning and modeling challenges. This SHRP2 suite of five products helps planners estimate travel demand in a way that integrates activities, networks, and the environment. Travel demand modeling systems can now reflect how travelers respond to congestion, travel-time reliability, and pricing, so decisions about operational improvements can be based on more reliable models. With better models, agencies can understand how operations can improve the function of their highway networks.

Today, planners address capacity issues, targeted investments, and operations strategies such as managed lanes, variable road pricing, ramp metering, variable speed limits, and other dynamic strategies. Traditional travel forecasting models do not adequately consider the effects of these dynamic transportation management strategies.

As technology has advanced, agencies have begun to adopt activity-based models (ABM) rather than trip-based models to forecast travel demand. Unlike traditional trip-based models, ABMs better capture the complexity of household travel schedules and patterns (e.g., taking a child to school, then going to work, then going shopping). Agencies have also begun to adopt dynamic traffic assignment models, which address travel through a network at a particular time (e.g., a trip at 7:30 a.m. is not the same as a trip at 7:45 a.m.).

A third thread of research has developed agent-based models, where travelers and other entities in the transportation system are represented by agents, who learn from interactions with each other and with the transportation network.



New approaches for evaluating dynamic strategies such as managed lanes.



Ultimately, travel-time reliability is critical to both freight and personal movement. As transportation policies and investments that affect travel-time reliability continue to gain strategic importance, decision-support tools and processes need to reflect their impacts.

Two products in the *TravelWorks* suite adapt current planning-centric, activity-based travel models to better consider travel time reliability and integrate them with current operations-centric, dynamic traffic assignment models. They are:

- **Improving our Understanding of How Highway Congestion and Price Affect Travel Demand (C04).**
- **Partnership to Develop an Integrated, Advanced Travel Demand Model and a Fine-Grained, Time-Sensitive Network (C10).**

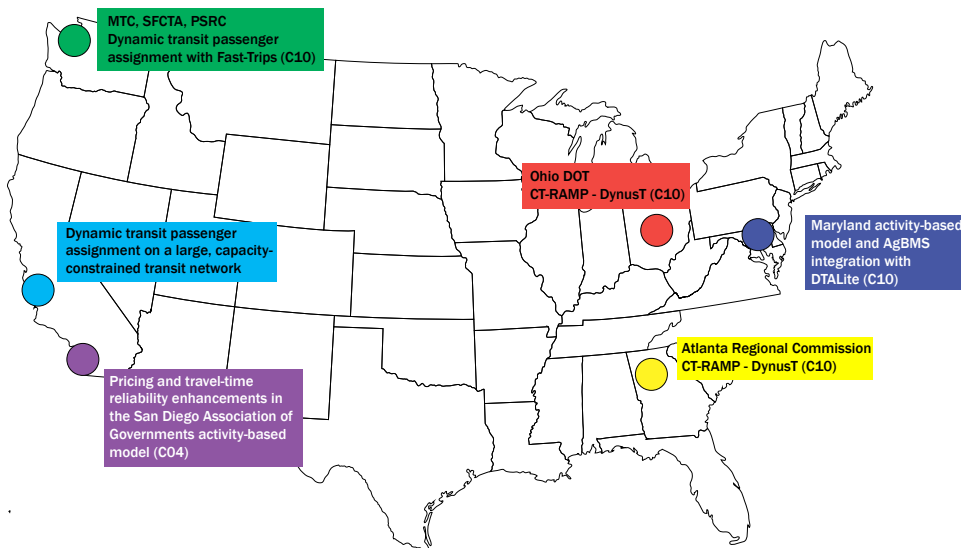
SHRP2 C10 also considers advanced agent modeling concepts that better represent how travelers learn and adapt to changing conditions.

In 2014 – 2016, as part of the SHRP2 Implementation Assistance Program, FHWA provided implementation assistance to five agencies to conduct four pilots and one lead adopter project exploring advanced integrated models:

- Two pilot projects – with Atlanta Regional Commission (ARC) and the Ohio Department of Transportation (Ohio DOT) – integrated an activity-based model (CT-RAMP) with dynamic traffic assignment (DynusT) in a highway setting.

- A pilot project – with Maryland State Highway Administration and Baltimore Metropolitan Council (BMC) – integrated the University of Maryland agent-based model (AgBM) with dynamic traffic assignment (DTALite), as well as a BMC's activity-based model (INSITE) with dynamic traffic assignment.
- A pilot project with Metropolitan Transportation Commission, San Francisco County Transportation Authority, and Puget Sound Regional Council implemented the Fast-Trips dynamic transit passenger assignment model.
- A lead adopter project with San Diego Association of Governments used the ideas from the SHRP2 C04 project to provide pricing and travel-time reliability enhancements to their existing ABM.

The nature of these projects warranted a formal evaluation process of the technology adaptations. Fortunately, the FHWA Exploratory Advanced Research (EAR) program had recently introduced Technology Readiness Levels (TRL) for EAR projects. TRLs, originally developed for NASA and Department of Defense projects, provide a common language for assessing the readiness of a technology for deployment – all the way from basic research, to applied research, to development and implementation. They were adopted for the SHRP2 C10 projects, and provided a structure for three peer reviews of the Maryland, Atlanta/Ohio, and Fast-Trips projects.

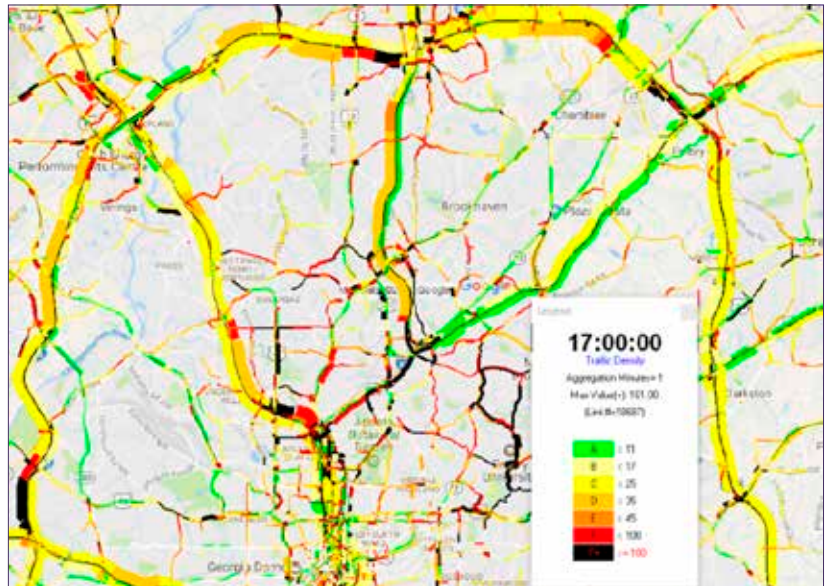


SHRP2 C10 and C04 Project Locations

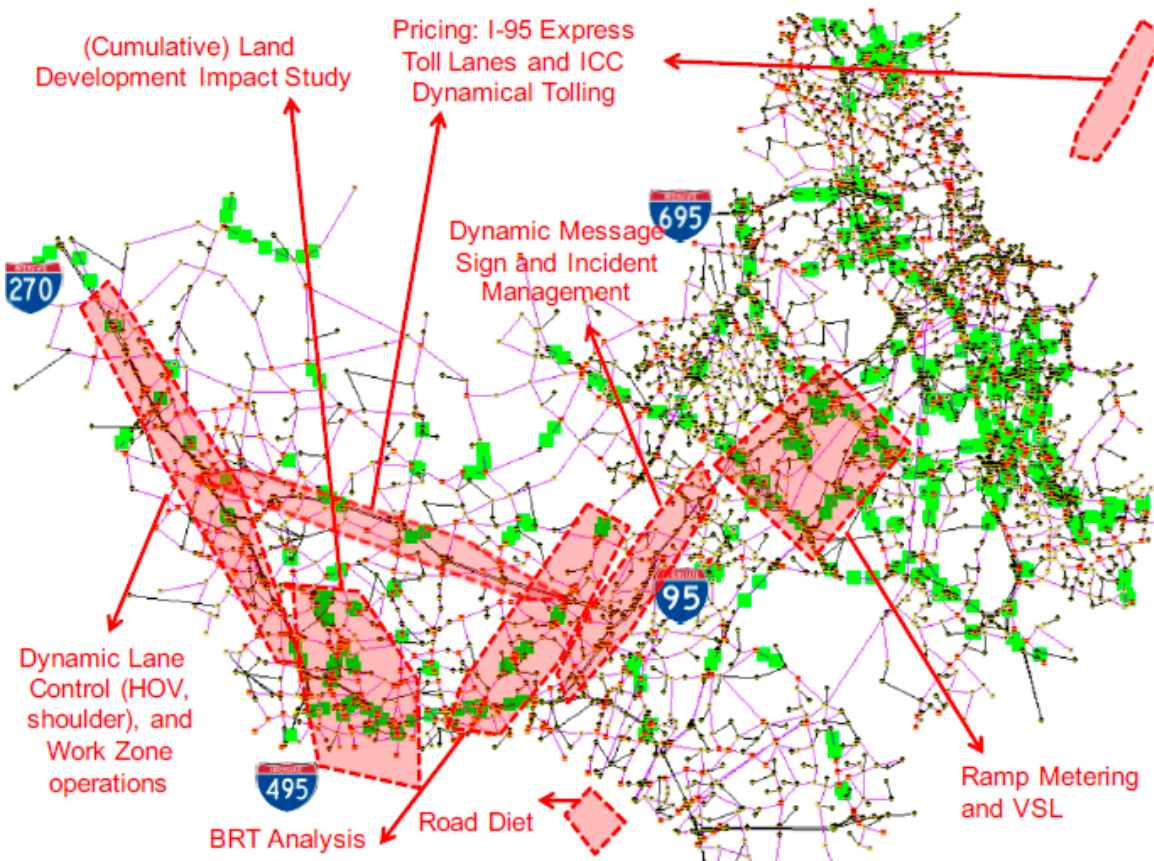
Technology Readiness Levels	
TRL 1 - 3 Basic Research	
TRL 4 - 5 Applied Research	
TRL 6 - 8 Development	
TRL 9 Implementation	

Each TRL peer review provided an in-depth introduction to the project to a panel of five outside experts. Panel recommendations included sharpening the identification of the questions that integrated models can uniquely address, comparing integrated model results with traditional model results, and formalizing run time and convergence criteria for the integrated models.

As was expected for these large pilot projects, the technology readiness was in the middle of the scale. An earlier version of the Maryland agent-based modeling work had received a TRL review in 2015. At that time, it was moving from basic to applied research. Now, it is moving from applied research to development.



Atlanta Traffic Density and Volume after I-85 Bridge Closure



Maryland AgBM-DTALite Applications

Applications of the integrated models include:

- A before/after study of changes in travel patterns as a result of the Interstate 85 bridge closure in Atlanta, to improve the agency's responses to unexpected disruptions.
- Several transportation system management and operations (TSMO) projects in Maryland.
- Use of Fast-Trips to model, evaluate, and predict transit line crowding and other service concerns in downtown San Francisco, to inform service planning decisions.

Ohio DOT is using the SHRP2 C10 package to develop an integrated model for a small city (Lima), and will release it for training and demonstration purposes.

The C10 and C04 work has also received significant exposure in the transportation planning and modeling community. In addition to local meetings and presentations at the TRB annual meeting, several conference sessions and webinars were organized for these projects. In May 2016, a Sunday workshop was devoted to the C10 projects at the Innovations in Travel Modeling conference in Denver. In May 2017, the Transportation Planning Applications conference in Raleigh, North Carolina had a session devoted to the C10 projects and a tutorial on Fast-Trips. During the first half of 2017, the FHWA Travel Model Improvement Program (TMIP) sponsored five well-attended webinars on the projects, whose recordings are available on the TMIP website.

Future Direction

Several project teams are now developing documentation and training for their local stakeholders. They will be working with FHWA to develop demonstration and training data sets. The *TravelWorks* product team will also be developing case studies that highlight both the technical advances and applications of the integrated models.

Behavioral User Equilibrium

Traditional travel models assume that travelers choose the route with the smallest generalized cost (which includes travel time). Equilibrium is reached when no traveler can unilaterally improve their own generalized cost by changing routes. We assume that travelers have perfect knowledge.

The Maryland agent-based model used a behavioral user equilibrium concept, which assumes that a traveler's knowledge is imperfect and improves based on travel experiences. Travelers search for better departure times, routes, and modes until their perceived time or cost gain from searching becomes less than their search cost. The Behavioral User Equilibrium concept works remarkably well for predicting how travelers adapt new travel patterns in response to system changes such as operational improvements in a corridor, new development patterns, or addition of a new toll road.

RELIABILITY

Championing predictable travel times



SHRP2 has been transformational for the field of transportation operations. We are in an era of rapid change in transportation. Big data and new technologies are enabling transportation agencies, travelers, and shippers to make smarter choices about transportation as both operators and users of the system. At the same time, there are challenges. In urban areas, our roads are increasingly stressed by the congestion that comes with growing population and development, and the associated unpredictability of how long a trip will take. Safety continues to be a key concern with the number of crashes on our roadways in both rural and urban areas.

With limited funding and space to make improvements, we need to get the most out of what we have by effectively operating our existing transportation facilities. The relatively low cost and shorter time for implementing transportation systems management and operations (TSMO) strategies makes them an attractive approach to addressing today's challenges. Effectively applied, TSMO can help agencies delay the need for system expansion and sometimes even alleviate the need for it.

Iowa Department of Transportation Director, Mark Lowe, explains it well, "TSMO is a concerted and proactive effort to operate the system at its highest and best capacity. It rests on a framework formed by the intersection of road weather management, traffic control, traffic incident management, and work zone management, and touches almost everything we do—from design, to field maintenance, to how we clear crashes and obstructions, and to how we help stranded motorists. TSMO is an essential part of delivering safe mobility, and when done

well it reduces crashes and increases flow and capacity without adding lane miles of roads."

This emphasis on TSMO is a change for agencies that were formed to design and construct roads and bridges. A transformation is needed. The SHRP2 Reliability research, products, technical/financial assistance, and leadership emphasis arrived at just the right time to help. While SHRP2 is not solely responsible for this transformation, a number of agencies found that SHRP2 served as the tipping point for advancing TSMO in their DOT. Many agencies had been trying to advance TSMO, and the SHRP2 products helped bring energy, attention, funding, and new tools/capabilities advance TSMO and create buy-in across their agency.

SHRP2 has helped agencies identify areas holding them back from advancing TSMO and implement solutions to better integrate TSMO into agency priorities, programs, and processes. With growing emphasis on TSMO came a growing awareness of the need to transform the knowledge and skills of the transportation workforce for TSMO; SHRP2 created significant new training and resources for the TSMO workforce. SHRP2 also highlighted the importance travelers and shippers place on the predictability of travel time and the value of using travel-time reliability in analyzing system performance and making decisions about current operations and future investments. This was a new kind of analysis, for which tools and data were limited until SHRP2 developed algorithms, software, and guides that help agencies integrate reliability.



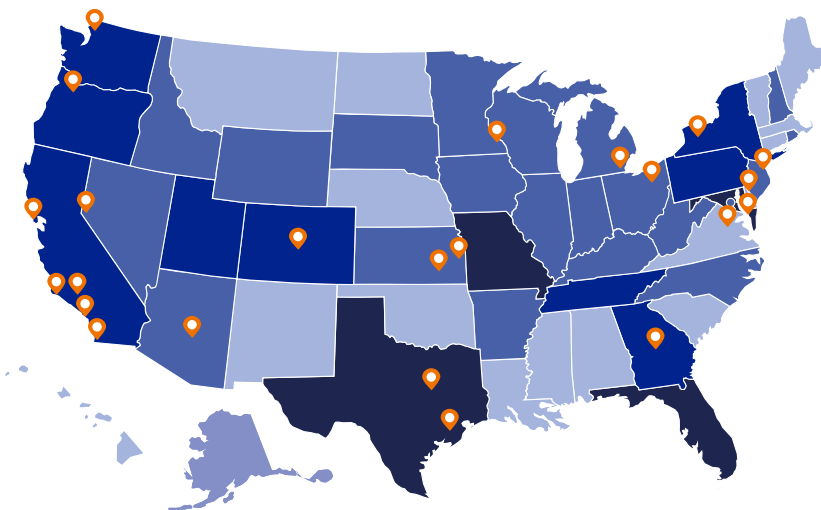
SHRP2 RELIABILITY SOLUTIONS

MAINSTREAMING TSMO ACROSS THE NATION

RELIABILITY PRODUCT IMPLEMENTATIONS

2-3	7-8
4-6	9-11

 REGIONAL



National Traffic Incident Management (TIM) Responder Training Program

TIM training is building stronger, safer, and faster traffic incident response teams across the country.

- > **302,000+** responders trained
- > **50** states, DC, and PR
- > **35** public safety academies use TIM training

Regional Operations Forums

ROFs have mainstreamed TSMO principles and practices by providing training and facilitating coordination among transportation agencies and their partners.

- > **10** regional workshops
- > **49** states have participated
- > **358** TSMO practitioner participants

TSMO Capability Maturity Assessments

CMM workshops are helping agencies assess their capabilities and develop mature TSMO business processes. 50 agencies have executed site-specific action plans to advance TSMO.

- > **32** State DOTs and Districts
- > **14** MPOs
- > **2** Border Crossings
- > **1** Transportation Management Center
- > **1** Turnpike Authority

Transportation agencies in all 50 states are incorporating transportation systems management and operations (TSMO) strategies to improve traffic flow and enhance their response to disruptive events.



POOR SIGNAL TIMING



SPECIAL EVENTS



TRAFFIC INCIDENTS



INCLEMENT WEATHER



WORK ZONES

These account for more than half of all congestion.

We were at a tipping point. SHRP2 helped us move from a point where TSMO was emphasized to where it was institutionalized. - Ryan Rice, CDOT TSMO Division Director

RELIABILITY FEATURE STORIES

Main-streaming Transportation Systems Management and Operations (TSMO)



In many areas across the country, transportation operations management was traditionally treated more as an afterthought to capital projects, at best approached on an ad hoc basis. TSMO strategies and equipment were deployed on a piecemeal basis, and these elements were typically among the first to get cut when budgets got tight. When it came to planning for TSMO, most efforts were limited to an intelligent transportation system (ITS) deployment plan or simply a list of projects. As a result, TSMO efforts tended to be more reactive, and funding for TSMO activities was sporadic at best. Some agencies recognized the need for change, but TSMO champions often had difficulty getting enough support for those changes.

As SHRP2 Reliability efforts progressed, the dialogue within state and local transportation agencies grew about the need for TSMO alternatives in addressing both recurring and non-recurring congestion. Thus began a conversation about the need for a more strategic approach to advance TSMO practices in states and localities. Throughout the dialogue, it became clear that TSMO needed to become institutionalized like other DOT programs, but it was still relatively new and sporadically deployed. From this came a study of more mature programs to determine what elements would be necessary for the advancement of TSMO, such as established processes, roles and responsibilities, identified skill sets and training, and performance metrics.

The Guide to Organizing Transportation Agencies to Advance Systems Operations and Management (LO6) offers a capability maturity model (CMM) framework that agencies use to conduct a detailed organizational self-assessment to identify ways to systematically improve their TSMO capabilities. This framework looks at six dimensions of capability: agency business processes, systems and technology, performance measurement, culture, organization and staffing, and collaboration. The CMM has quickly become a valuable tool for helping agencies advance TSMO. According to Scott Marler, Iowa Department of Transportation director of traffic operations, “The CMM has been central to Iowa DOT’s approach to TSMO. Using the model, we were able to get a picture of how mature we were as an agency, which in turn has helped focus our efforts on those areas that needed to be addressed. We continue to use the model to review our work and further refine our approaches to managing and operating the transportation system, with the goals of delivering safe mobility and getting our customers there safely, efficiently, and conveniently.”

Through the SHRP2 Implementation Assistance Program (IAP), 23 states and Washington, D.C. have implemented the CMM. Other states and regions have expressed interest in the CMM, and use of the tool has grown well beyond the original SHRP2 IAP sites. In total, FHWA has supported CMM assessment workshops in more than 50 sites that include statewide efforts with state DOTs and regional efforts such as individual DOT districts and MPOs.

“The CMM offers us a quick and comprehensive tool to allow our region to identify key issues that are holding back our ability to grow as a region. Thinking within the structure of the CMM had us look at our region from a different perspective, moving us away from the technology, and into how the large system works well and what areas needed work. Through the process, we have been able to identify low and no cost issues that we could handle at a staff level. We continue to iterate as we accomplish tasks, adding new items, and ensuring our activities stay relevant.”

Jeremy Dillmore, Florida DOT District 5

Use of the SHRP2 CMM has led to a movement to better integrate TSMO into the planning process and develop stronger, more established TSMO programs. The majority of SHRP2’s IAP sites decided to develop a TSMO program plan as a result of their CMM self-assessments, making it the most frequent item in site action plans. These efforts to mainstream TSMO into an agency’s culture and business processes are transformational.

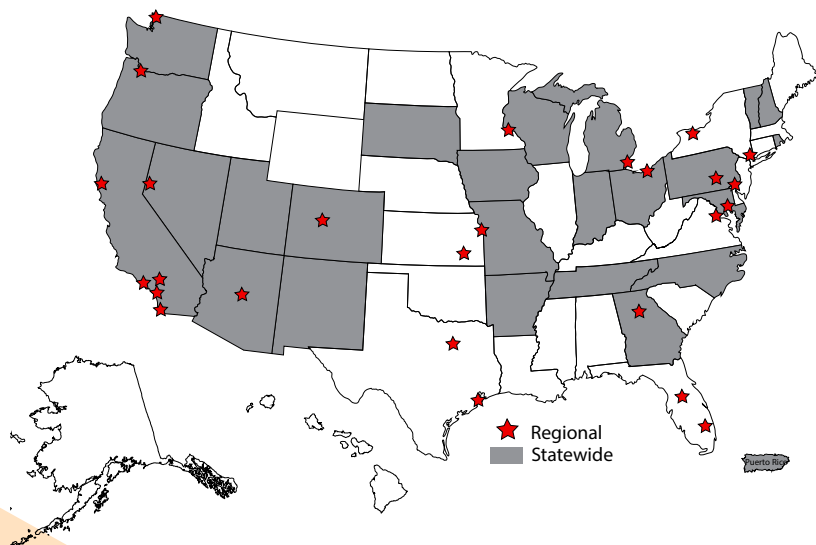
One key element identified was the need to develop a strategic and programmatic approach and incorporate TSMO as early as the planning process. Many states and MPOs have developed TSMO strategic plans or TSMO program plans. The intent of these plans is to set goals, objectives, and a path forward to advance TSMO in the state or region, similar to strategic plans for more

established programs. TSMO program plans also involve programmatic elements such as organization and process changes, establishing funding sources, identifying key partners, developing metrics, and other institutional advances that are critical for success, including tactical elements such as specific projects to implement TSMO strategies.

The development of the TSMO plan concept had inspiration from other successful models. For example, the Safety discipline developed the *Strategic Highway Safety Plan* to establish goals and objectives, a collaborative process among key stakeholders, and dedicated funding. Applying this and other models to TSMO led to further research through the National Cooperative Highway Research Program that provided a framework for developing a TSMO plan. While there is not a single plan that is applicable to every situation, this study provided questions and components to consider while recognizing the need for flexibility to consider state and local dynamics, such as:

- Who will lead the process? Who will be consulted? How will decisions be made? What role will the MPOs have? What role will FHWA have?
- How will we involve all the key units in the department (e.g., planning, maintenance, construction, regions)? How will we ensure that each unit feels ownership when it is time for implementation?
- Will this duplicate existing plans? How will this plan be linked and coordinated with existing plans (e.g., Strategic Highway Safety Plan, Long Range Transportation Plan, ITS deployment plan)?

CMM Workshop Sites



- What existing planning and decision-making processes need to be considered, incorporated, or accommodated (e.g., departmental strategic planning, Statewide Transportation Improvement Program, congestion management processes, legislative or regulatory initiatives)?
- How will we coordinate TSMO program planning and development with other initiatives (e.g., asset management, performance measurement, and sustainability)?
- How will we measure success? What will an A+ result look like?

“Florida DOT District 5 targeted TSMO planning as our primary area of interest both from a staff level and a management level. Staff saw the opportunity to get involved early on in projects as being the least disruptive to the work program and a way to get buy-in inside the Department, with partner agencies, and the public. Management saw the opportunity to achieve short term implementations of improvements on critical corridors.”

Jeremy Dilmore, Florida DOT District 5

Diversity in Approaches

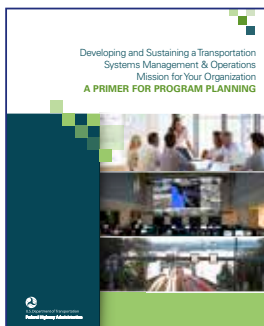
Currently, state and local agencies in about half the states have completed a TSMO plan, are currently developing one, or have integrated TSMO plan elements into their current planning processes. Each site has crafted its own unique approach to improving system performance in its own locality. For example, given their geographic sizes and extensive decentralized organization structures, both Texas DOT and Florida DOT have developed statewide TSMO strategic plans that provide an overall framework for each of their districts to develop its own TSMO program plan. Conversely, a statewide TSMO strategic implementation plan was the choice of a centralized state like Maryland, which established vision, mission, goals, objectives, and strategies.

In yet another approach, Iowa DOT chose to develop three separate TSMO plans. Iowa’s TSMO Strategic Plan highlights the state’s challenges, makes the case for TSMO, and describes the vision, mission, goals, and strategic objectives for TSMO. Its TSMO Program Plan builds on the Strategic Plan by providing the structure for a comprehensive TSMO program. The Program Plan outlines the programmatic objectives, strategies,

processes, procedures, and resources needed to deliver the vision and goals of the TSMO Strategic Plan. From there come the Service Layer Plans that include discussion and analysis of opportunities and challenges, existing conditions assessment, gap analysis, recommendations, and a detailed 5-Year Service Layer Plan cost estimate for actions in each of the eight service layers identified.

While these efforts were primarily driven from the SHRP2 CMM sites, FHWA has supported the nationwide TSMO program planning efforts through TSMO program roundtables and virtual peer exchanges over the past two years. In addition, FHWA has developed a primer and a new workshop to help agencies who are starting to develop plans.

To gauge the impact of the CMM effort, over the past year FHWA worked with each of the 23 SHRP2 IAP sites to conduct a re-assessment. Each agency measured their progress on their original CMM action plan and assessed their current level of capability in each of the six CMM dimensions, comparing their current ratings to



The FHWA developed
Designing and
Sustaining a
Transportation
Systems Management
& Operations Mission
for Your Organization:
A Primer for Program
Planning.

“Iowa’s TSMO plan is composed of three important parts, the strategic plan, the program plan, and the tactical plans. We have eight tactical plans, which we call ‘service layers’ because they are designed to provide services to our customers and include items such as traveler information, work zone management, and connected/autonomous vehicles to name a few.”

Scott Marler, Iowa DOT director of traffic operations

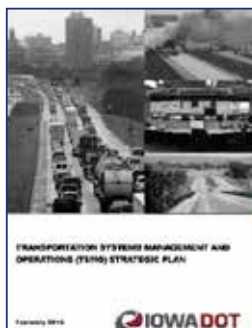


Photo courtesy of Washington State DOT

where they rated themselves a few years ago. The results make it clear that the CMM and other SHRP2 efforts have made an impact in state and local agencies, who are:

- Focusing increased effort on TSMO planning and the development and mainstreaming of TSMO programs.
- Encountering success in gaining buy-in and support from senior leadership and key stakeholders.
- Re-organizing to elevate TSMO and make it a higher priority in some state DOTs, and even creating positions to lead TSMO efforts and units that report directly to senior leadership.
- Re-evaluating their existing partnerships with other public agencies, including law enforcement, to incorporate TSMO goals and objectives.
- Revising agency performance measures and dashboards to include TSMO.
- Adding TSMO metrics such as travel-time reliability and TSMO review steps to their project evaluation processes during planning and design.

While the concept of TSMO planning is still evolving, positive progress is already evident. As a result of the SHRP2 CMM effort, discussions are taking place between planners, operators, and other key groups to incorporate TSMO strategies into project planning and congestion management. It's now more widely recognized that state and local agencies can no longer build their way out of congestion, and that TSMO can provide key, cost-effective solutions.



Many states have developed TSMO plans, including Iowa, Maryland, Missouri, and Texas have developed TSMO plans.



Similar Assessment Tools for TSMO Strategies

Through use of the CMM assessment tool and its popularity, interest arose for similar tools that assess capabilities in specific TSMO strategy areas. FHWA developed six companion tools that are structured like the CMM. These Capability Maturity Frameworks and interactive online tools have been developed for:

- Traffic Management
- Traffic Incident Management
- Road Weather Management
- Planned Special Events
- Work Zone Management
- Traffic Signal Management

The frameworks and tools help agencies assess current capabilities and generate a set of targeted activities to strengthen their operations programs. The frameworks and tools are available at <https://ops.fhwa.dot.gov/tsmoframeworktool/index.htm>.



Workforce Development Focused on TSMO Helps Agencies Prepare for Today and the Future

Reduced funding and increasing transportation improvement needs — these two realities go hand in hand for most transportation agencies. One approach agencies have identified to help them bridge the divide between these two challenges is transportation systems management and operations (TSMO). TSMO offers solutions to help address these seemingly impossible challenges through cost-effective strategies to help better operate the transportation system to get the most of the facilities we already have built. Ultimately though, according to Patrick Son, managing director of the National Operations Center of Excellence (NOCoE), “TSMO is really a culture change.”

Like any culture change, TSMO needs knowledgeable people to help it take hold as a core business function in transportation agencies. As three NOCoE white papers on the workforce environment for the TSMO community highlighted, there is a significant need for new resources to develop the workforce’s knowledge, skills, and abilities in TSMO. This need applies to today’s transportation workforce and the TSMO workforce of tomorrow. Bringing agency staff up to speed on many of the concepts and procedures required for a successful TSMO program can be a daunting challenge, and there was a recognized need for new resources to help develop personnel in the knowledge, skills, and abilities fundamental to jobs in the field of TSMO.

SHRP2 Reliability tackled some of these issues head on. Through SHRP2 Reliability’s creation of robust training programs like the **National Traffic Incident Management (TIM) Responder Training Program (L12/L32)** and the **Regional Operations Forum (ROF) (L36)**, the transportation community has a growing set of resources to help agencies enhance the knowledge, skills, and abilities of their organizations to advance TSMO. These courses not only provide valuable information on key TSMO practices, but also provide a great opportunity to develop a network with other TSMO professionals and learn from their experiences. Another key resource for TSMO professionals is the National Operations Center of Excellence (NOCoE), launched with the support of the SHRP2 effort **Framework for Improving Travel-Time Reliability (L17)**. The NOCoE is now entering its fourth year of operation and offers online resources, webinars, and peer exchanges to share knowledge and experiences about TSMO. The NOCoE site averages 3,022 visitors a month (a 40 percent increase over the year before), and is on pace for 100,000 total page views in 2017, up 32 percent from 2016. With its growing awareness and use, the NOCoE is quickly becoming an important resource for the TSMO workforce.

Basic Training: Capturing Student Interest in TSMO

Before taking their places behind the desks of a traffic operations center, future transportation professionals should be familiar with the technologies, strategies, and practices of TSMO. The NOCoE is taking a lead on pre-employment outreach at community colleges, universities, and graduate schools to see how TSMO can be better incorporated in their curricula. In November 2017, the NOCoE brought together a select group of TSMO champions in academia to help determine what materials are needed by instructors to integrate TSMO principles in the classroom and how to attract more students to TSMO-related areas as technological advancements continue.

Interestingly, it is one of the post-hiring trainings that captures the attention and imagination of these aspiring operations practitioners. The real-world success of the *National Traffic Incident Management (TIM) Responder Training (L12/L32)* SHRP2 solution helps with those pre-employment outreach efforts. “TIM in general is a great conversation starter to show TSMO in action for someone who’s relatively new to TSMO,” says Patrick Son, managing director at the NOCoE. “It’s one thing to send someone the business case primer, but it’s another thing to give them a real-world example of why we’re working in TSMO.”

When asked, 81 percent of those who completed the SHRP2 National Traffic Incident Management Responder Training Program said they felt safer overall as a result of the TIM training, and 87 percent believe they have stepped up their efforts to minimize secondary crashes at traffic scenes since attending TIM training. Endorsements like this show that TIM training is having a real impact.

Equipping Today’s TSMO Professionals through SHRP2

TIM Responder Training (L12/L32)

With more than 300,000 responders trained in TIM in all 50 states, Puerto Rico, and Washington, D.C, the SHRP2 TIM training is having a broad reach and impact with the range of practitioners involved in clearing incidents. This milestone was recognized by Transportation Secretary, Elaine L. Chao, during a November 2017 event at U.S. DOT’s headquarters involving representatives of the responder community: “Enhancing training and boosting preparedness saves lives. Today I am glad to report that 300,000 responders nationwide completed the TIM training. It’s appropriate that you’ve reached this milestone during National Traffic Incident Response Awareness Week.”

Clearing incidents more safely and quickly helps ensure personnel from law enforcement, fire/rescue, emergency medical services, towing and recovery, transportation and other disciplines go home safely, and that our transportation system operates more smoothly and with fewer crashes and delays.

Over a quarter of the more than 1,000,000 responders in the United States who work on our roadways have now taken the SHRP2 training and are seeing its benefits. In some states, more than 40 percent of the responder population has been trained through a network of trainers developed by the SHRP2 train-the-trainer program.



U.S. DOT Secretary Chao speaks during National Traffic Incident Response Awareness Week to commemorate the milestone of 300,000 responders trained by the SHRP2 *National TIM Responder Training Program*.

Photo courtesy of Tracy Scriba, FHWA



Former New Hampshire Department of Transportation Commissioner, Chris Clement talks to the ROF group about TSMO from a CEO perspective.



Groups working together at the Regional Operations Forum in Phoenix in February 2014.

Photos courtesy of Kathleen Frankle, CATT

The TIM training was put into action in May 2017 when a fuel tanker carrying 1,000 gallons of diesel fuel and eight different oils blew a tire and crashed and caught fire on Interstate 25 in Colorado. After two Colorado Department of Transportation employees rescued the driver and put him into a nearby ambulance, the well-coordinated work of local police, firefighters, hazmat specialists, county deputies and the Colorado DOT cleared the roadway and began repair. The damaged roadway was repaved and all lanes were reopened before the following morning's rush hour. Coverage of the event noted that responders from different agencies were able to more effectively work together thanks to the SHRP2 TIM training.

Regional Operations Forum (L36)

Post-hiring professional development is a complex undertaking aimed to increase TSMO capabilities and elevate TSMO as a core transportation function, rather than as an afterthought to capital projects. The *Regional Operations Forum (ROF)* (L36) solution was developed to serve as a platform for mainstreaming TSMO through knowledge sharing and peer exchange. The University of Maryland's Center for Advanced Transportation Technology (CATT) conducted the SHRP2 research for L36 and has been instrumental in developing, modifying, and reporting on the ROFs. The forums are held regionally in a cross-disciplinary, immersive format with participants from neighboring states and their partner agencies. This networking aspect is very important in the effectiveness of the ROFs, with many participants saying they learn just as much from the discussion and exercises with their peers as they do from the expert presentations. "You can't do TSMO in a vacuum. It touches many areas and you have to

reach out to other departments in the DOT," stated Kathleen Frankle, program manager at the University of Maryland's Center for Advanced Transportation Technology (CATT). Through SHRP2, every state, the District of Columbia, and Puerto Rico have been given at least one opportunity to send participants to an ROF. In total, 358 TSMO practitioners from across the country have participated in ROFs to date.

Over the original five-day ROF format, attendees were guided through the development of TSMO implementation plans that they could take back to their organizations. These skills, knowledge, and plans were shared within and across organizations in a region, thereby achieving an "exponential increase" in the reach of the ROF training. "In two to three years, the same number of people attended the ROFs as had attended the National Operations Academy over a nine-year period," observed Frankle. "This dramatically increases the number of agency personnel exposed to TSMO concepts. TSMO is really a mindset and the more people within an agency that are exposed to TSMO, the better the chances of the concepts being implemented in all areas of the agency." Participants have also found the ROF provided more excitement and momentum for TSMO in their agencies because several people went to the same ROF and came back excited to share their knowledge and move forward on their implementation plans.

Today, efforts continue to expand use of the ROF to equip the TSMO workforce. Working with DOTs in two IAP states – Washington and California – CATT is working to create some online training based on the ROF to make TSMO knowledge more accessible to more people.

The Kansas Department of Transportation is leading another IAP project funded by SHRP2 to offer a monthly TSMO training program based on the ROF to its own staff and the other four states in ITS Heartland (Iowa, Missouri, Nebraska, and Oklahoma). Some of the monthly sessions are delivered virtually and some are delivered in longer in-person sessions that allow for more extensive discussion across the five states. The IAP project includes recording the sessions and making them available online for the benefit of other DOT staff and partner agencies as well as future staff. In addition, FHWA is working with AASHTO to create a second-generation format of the ROF that still includes the broad range of TSMO material and peer interaction but spreads that across more extensive pre- and post-ROF programs

and a shorter in-person component. This should help more people participate in an ROF while managing the competing demands of travel costs and time away from the office and home.

The positive impact of the ROF and SHRP2's work to entrench and transform the cultures of transportation agencies for TSMO is starting to show. "In the past, we would see participants with titles such as traffic management center manager, ITS system director, operations engineer, etc. participating in the National Operations Academy," said Frankle. "Now, over the last few years we have had some participants with TSMO in their title, such as assistant state engineer for TSMO, TSMO program manager, and TSMO engineer. It's very exciting to start to see the transition."



Equipping Today's TSMO Workforce – In the Words of ROF Participants

DESIGN:

This course was an intensive introduction to TSMO for me. I will definitely use what I learned to not only try to include TSMO items in future design but collaborate with the ITS personnel to help implement TSMO in design. –
Traffic Engineer, Oklahoma Department of Transportation

ENFORCEMENT:

As an enforcement officer, it was a very useful forum. Understanding what DOT engineers do with the various traffic systems will help me in the future. –
Major, Highway Police, Arkansas Department of Transportation

SAFETY:

The program sensitized and increased my awareness of the importance and the benefits that can be gained from TSMO. –
Acting Traffic Safety Manager, District Department of Transportation

PEER NETWORKING:

In addition to the classroom training, the opportunity to network with state peers was invaluable. Some of peers have already developed solutions to problems I am currently dealing with. I cannot wait to return to the office and implement some of the concepts and ideas I have learned while attending this program. –
Operations Engineer, North Carolina Department of Transportation

OVERALL:

The course materials were useful and it was great seeing so many aspects of TSMO rolled into one, when you are used to treating many of the aspects separately. –
ITS Engineer, Nebraska Department of Roads

Reliability's Increasing Role Throughout Transportation



Since the turn of the millennium, transportation agencies have been giving increasing attention to travel-time reliability and measuring how travel time varies over time. Understanding that there is no such thing as “normal,” and that average travel times do not accurately reflect what travelers experience, agencies have begun to look at reliability as a key measure of system performance. Reliability has long been used as a performance measure in transit, and it is now considered a key measure of roadway performance. To achieve substantial, measured improvements in system performance, agencies across the nation must learn how to expect the unexpected and use that understanding to improve system-wide reliability.

SHRP2 identified reliability as a key focus area, with research showing that the predictability of travel time is as important to road users as travel time itself. Many of the causes of unreliable travel times are system disruptions such as crashes, road work, and bad weather—and all of these are addressed by operational strategies. “Better operations helps improve congestion levels, but reliability is where operations services and strategies really shine. If you don’t measure travel-time reliability you miss some of the key benefits of operations,” said Tracy Scriba, FHWA’s SHRP2 Reliability program manager.

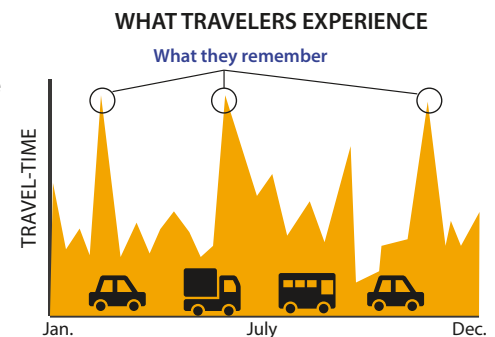
Incorporating Reliability in Planning and Decision Making

One of the key accomplishments of SHRP2 was to develop analytical approaches, algorithms, and data requirements to analyze travel-time reliability and incorporate reliability analyses into new and existing modeling tools. Travel-time reliability analysis is a world of big data, collaboration, and scenarios. Analyzing travel-time reliability means looking at the variability over time –often in the form of travel time distributions

and indices. Averaging large data sets into typical conditions is not realistic, as is done traditionally for standard congestion analysis, since what the analyst is studying is precisely the variability that is lost when averaged. Once a travel-time reliability issue is identified, other data such as crash history and weather events are needed to drill down and diagnose the causes of the travel variability and to determine appropriate mitigation strategies. These data sets may come from sources outside the transportation agency and require additional collaboration. These data can also be used to develop a set of scenarios to use in predictive analyses, such as for estimating the reliability benefits of potential transportation improvements under rainy conditions when crashes are more likely.

In the ***Reliability Data and Analysis Tools (L05/L02/L07/L08/C11)***, SHRP2 created a diverse set of products designed to help agencies gather travel-time data, estimate the economic and travel-time benefits expected from adopting reliability as a key consideration, and integrate reliability considerations into their transportation decision making. These products:

- Help agencies develop reliability monitoring programs (L02) and incorporate reliability into their planning and programming processes (L05).



- Offer spreadsheet tools for analyzing how design strategies can improve reliability (L07) and estimating the regional benefits to reliability from transportation improvements (C11).
- Incorporate reliability into the highly used Highway Capacity Manual and the Highway Capacity Software to analyze the reliability of facilities and strategies (L08).

There is clearly growing interest in these tools, with the 7 pilot sites during Round 4 of the IAP increasing to 13 lead implementer sites in Round 7. The state of Florida was one of the SHRP2 IAP pilot sites. Florida is the third most populous state in the United States. With more than 20 million residents, the state's transportation system is managed in a decentralized approach by the Florida Department of Transportation (FDOT) and 27 MPOs. FDOT has been looking at reliability since the 1990s and has developed a 4-dimensional model of mobility performance:



While people are generally receptive to the idea of the importance of reliability, many tools and a lot of work are needed to effectively incorporate and regularly use reliability in transportation projects, planning, and operations. This was a key finding uncovered by FDOT in its pilot of the **Reliability Data and Analysis Tools (L05/L02/L07/L08/C11)**. These tools calculate base reliability conditions and then enable the user to analyze the effectiveness of a variety of treatments by providing fairly simple input data regarding the treatment effects and cost parameters. As outputs, these tools predict cumulative travel-time index curves for each hour of the day, from which other reliability variables are computed and displayed. The tools also calculate cost-effectiveness by assigning monetary values. For

example, the **Reliability by Design (L07)** tool allows the user to input data regarding site characteristics including geometry, traffic demand, crash history, and weather, and analyzes a generally homogeneous segment of a freeway (typically between successive interchanges) for the impacts of potential design features or changes.

As part of their work with the **Development of Improved Economic Impact Analysis Tool (C11)**, FDOT and the Hillsborough MPO developed a post-processing travel demand modeling tool focusing on travel-time reliability and safety. The tool has been used in Tampa as part of its Long Range Transportation Plan update to assess the reliability impacts of potential projects, including operations projects that were identified in the plan. FDOT has done some training with the tool and hopes to host additional training courses for the Florida MPOs on the use of the tool.

The Handbook for Incorporating Reliability Performance Measures into Transportation Planning and Programming (L05) provides an overview of procedural and technical approaches for state DOTs and MPOs to integrate mobility and reliability performance measures and strategies into transportation planning and programming processes. In its pilot, FDOT matched up the L05 product with FDOT's policies and programs to identify areas of improvement in implementation. "What we found through testing L05 is that for reliability to be successfully implemented, it needs to occur in all planning and production phases and when the districts evaluate and recommend or select projects," said Anita Vandervalk, subject matter expert for FDOT.

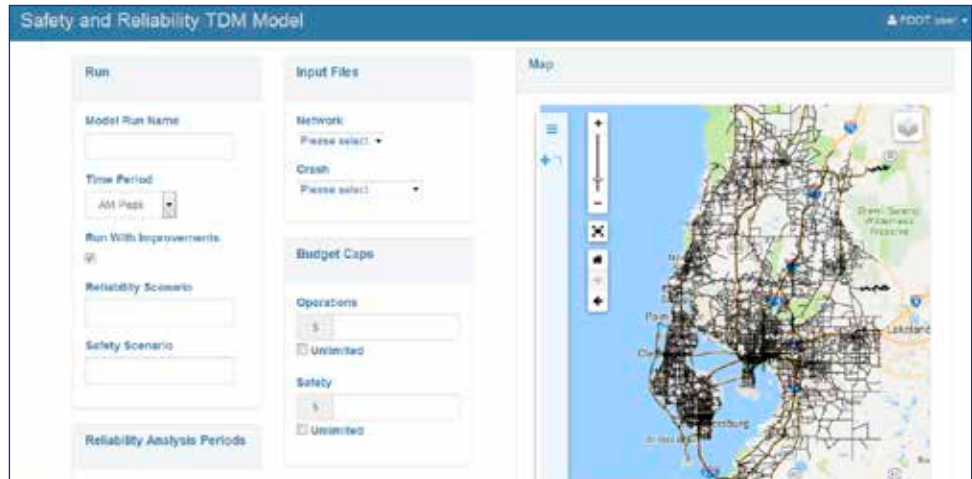
As a result of its work piloting *Reliability and Data Analysis Tools*, FDOT developed the *Planning for Travel Time Reliability Guide*. This guide helps FDOT employees and consultants better understand how travel-time reliability is incorporated in the DOT's planning processes for capacity expansion and operational improvements. The guide also highlights opportunities for collaboration, shows tools for incorporating travel-time reliability, and explains how to fund improvements that address travel-time reliability. FDOT's guide also presents the different performance measures that address travel-time reliability and summarizes Florida's Mobility Performance Measures Program and how it incorporates travel-time reliability. FDOT is conducting

outreach activities to ensure these tools are available to its MPOs, and presentations are scheduled to share lessons learned with agencies across the country. Doug McLeod, FDOT planning manager for mobility performance measures says, “Ultimately we foresee these products helping us address the applicability of transportation reliability performance measures for our own purposes as required by MAP-21 and the FAST Act.”

Reliability on the Roadways

As important as integrating reliability is in operations and planning, it is also helpful to effectively communicate travel-time reliability information to roadway users. SHRP2’s **Communicating Traveler Information and Estimating Its Value to Travelers (L14)** was developed based on the idea that agencies can reduce congestion and improve reliability by helping travelers make travel choices that take into account travel-time variability. This project created a travel-time reliability lexicon for effectively communicating reliability traveler information to the public. Reliability differs from typical traveler information because reliability is best used when planning a trip for determining the best route and departure time, or when making siting decisions such as where to locate a business or buy a house within a region where the travel times are more predictable. Once a traveler has started on a trip, the actual current travel time at that day and hour tends to be more critical.

Three regions—Houston, TX; Columbus, OH; and Raleigh/Durham, NC—pilot tested several message sets from the lexicon by providing reliability traveler information through existing 511 systems, traveler websites, and a smartphone app, and then gathering feedback from users. Based on the results of the pilot tests, SHRP2 has created a workshop and a guide to help other agencies understand how to provide travel-time reliability information to users.



Screen shot of the main input screen for the post-processor tool Florida developed based on the SHRP2 C11 tool. It allows users to set up the parameters for a reliability analysis, using the results from a travel demand forecasting model as the basis.

Source: FDOT

Beyond the helpful information sharing among peers, the workshop highlights the travel-time reliability lexicon and tips from the pilot tests. The guide, *Disseminating Traveler Information on Travel Time Reliability*, identifies options and recommends the best terminologies for specific communications tools, including websites, dynamic message signs, mobile apps, and 511 systems.

“I’ve participated in many TSMO and traveler info meetings and workshops – but the language has been my question for a long time now – thank you!”

Attendee from the Traveler Information on Travel-Time Reliability (L14) workshop

Really considering the reliability of travel times is truly a transformation in transportation, which is why the SHRP2 Reliability focus area developed a comprehensive suite of solutions to assist decision makers, analysts, operators, responders, and the public. Looking ahead, SHRP2 Reliability Program Manager, Tracy Scriba states, “By elevating the role of reliability in organizations and in technological tools, we can make significant advancements to improve traffic flow and get the most out of our existing infrastructure and the capacity of the transportation system.”

SHRP2: IN THE CLASSROOM



Incorporating SHRP2 Solutions into Academia

SHRP2 Solutions have the power to change the way transportation agencies do business, but they also have the power to turn the state of the art into the state of the practice when they are introduced to the next generation of transportation professionals while they are still learning their trade. These products fit not only into traditional transportation curricula such as engineering and planning, but also into disciplines such as urban planning, economics, computer science, physics, and others. Further, by educating young transportation professionals about the products, the SHRP2 Education Connection indirectly supports the widespread dissemination of knowledge about SHRP2 Solutions into transportation and private sector firms where graduating students will be employed.

During the first round of the SHRP2 Education Connection in 2015, 10 institutions brought 22 SHRP2 products or product bundles into classrooms across the country. Building on that success, FHWA awarded a

second round of grants during the summer of 2017. The five universities listed below received cooperative agreements to integrate products from three SHRP2 focus areas into their curricula. All awardees will present their findings and experiences at the 2019 TRB Annual Meeting.

The University of Arkansas – Fayetteville (UA), which was previously awarded Round 1 funding, has begun its Round 2 work to incorporate seven SHRP2 products into undergraduate and graduate-level civil engineering courses. At the undergraduate level, UA plans to add modules that address selected Renewal, Reliability, and Capacity focus area products. Graduate-level courses will include the newly enhanced undergraduate course content plus additional instruction on advanced solutions within the Renewal and Capacity focus areas. Several SHRP2 products will be presented across multiple courses to provide a connective web between junior- and senior-level courses. In addition to developing standard course

materials – lectures, case-based learning activities, and out-of-class assignments using SHRP2 analysis tools – UA will also produce a recorded webinar that will detail how the SHRP2 products were implemented into the curriculum, describe the challenges and successes encountered in student learning and teaching approaches, and highlight lessons learned. This webinar will be shared with the TRB Standing Committee on Transportation Training and Education (ABG20), which can support dissemination throughout academia and potentially spread the educational materials to universities where SHRP2 products are less well-known.



At **California State University** – Los Angeles (CSULA), the departments of civil engineering, computer science, and electrical engineering will team up to design undergraduate and graduate course content, lesson plans, learning outcomes and assessment plans to implement SHRP2 Renewal and Reliability products in a wide range of courses. Products will be incorporated into courses in the pavement engineering, civil engineering materials and laboratory, transportation engineering, intelligent transportation systems, and data science concentrations. Course materials will include subject-oriented lectures, project-based content, laboratory implementation, and field visits.

CSULA will explore the possibility of developing an online platform, which will potentially allow for sharing the course materials with other departments, increasing the exposure of the SHRP2 innovations to a broader academic audience. Due to the multidisciplinary nature of the SHRP2 Solutions, CSULA sees great potential for incorporating the research results into different majors outside the engineering disciplines, such as geology and earth science, mathematics and statistics, sociology, physics, mechanical engineering and technology. By sharing these products more broadly, students from different colleges and departments will have the opportunity to observe and understand the application of the SHRP2 innovations in the field of transportation.

The North Dakota State University – Upper Great Plains Transportation Institute (UGPTI) will modify existing curricula and deliver innovative educational materials by incorporating products from the Capacity focus area. UGPTI's approach uses a hybrid format of online and traditional classroom instruction. Revised modules will enable the transportation and logistics program to include the latest state-of-practice applications and information. Modules will be relevant to the existing curricula in numerous departments, such as civil and environmental engineering, construction management, and architecture and landscape architecture. Through these new modules, students will be exposed to new tools, processes, and innovations that address emerging transportation issues and challenges. The courses incorporating the SHRP2 products will be shared as a whole package and as sub-packages among other members of the Mountain Plains Consortium, a collection of eight university transportation research centers in Wyoming, Colorado, Utah, and North and South Dakota that is sponsored by the U.S. Department of Transportation. Packages are composed of entire training courses, while sub-packages

are the specific outputs of the SHRP2 enhancements that have been integrated into the current curriculum. They include all presentation files with notes, exam materials, and evaluation template. UGPTI will also share the integrated course syllabus.

The goal of **Rowan University's** Round 2 effort is to build upon its successful integration of SHRP2 products in Round 1 by expanding the scope to an even wider academic audience. Rowan hopes to excite a diverse population of students about potential careers in transportation engineering through the use of SHRP2 products, which have a very high “cool factor” among young people due their advanced nature. In part, this will be achieved by strengthening the vertical integration of SHRP2 products into the curriculum; providing hands-on, in-depth modules of select SHRP2 products in junior-, senior- and graduate-level transportation courses; and collaborating with instructors from Villanova, Temple, and West Virginia Universities to implement a vertical integration framework into their curricula. In addition to sharing SHRP2 modules with these other universities, Rowan will help disseminate knowledge about SHRP2 products by integrating selected SHRP2 Solutions into the National Summer Transportation Institute program, which will expose high school students to the products and demonstrate tangible benefits in students' daily lives. Rowan will also organize a TRB webinar to present the outcomes of the project and encourage other institutions to adopt their proposed SHRP2 integration framework.

The University of Idaho (UI) is incorporating products from the Capacity and Reliability focus areas into its transportation engineering coursework to create a compendium focused on these two themes, which deal with planning and operations respectively. One of the main goals of UI's efforts will be to encourage future information-sharing and cross-communication by providing a broad range of tools and resources that can be “plugged and played” in different classroom environments by different instructors. Instructional methods will include classroom lectures, assigned study exercises, student evaluation rubrics, and instructor notes to maximize opportunities for transferability across instructors and institutions. UI will seek out and foster networking opportunities to actively promote these materials by participating in and speaking at other national conventions or academic forums focused on science and engineering where SHRP2 educational products can be highlighted.

SHRP2



The Road to Success

Strategic foresight and partnerships

For the past five years, SHRP2 has been breaking new ground by identifying and implementing innovative approaches to improving the way we move people and goods throughout our transportation infrastructure. SHRP2 was the first research program of its size and complexity to strategically focus on changing the way transportation agencies do business, not only using new technologies but also new processes and business models to help transportation professionals address common challenges.

Researchers in all fields will agree: research is fascinating. But research for the sake of research can be a road to nowhere. By contrast, SHRP2 research was planned and conducted with the goal of successful implementation in order to achieve substantial cost, efficiency, and safety improvements in the four strategic focus areas. To this end, SHRP2 programs incorporated stakeholders from state transportation agencies, academia, planning organizations, and the transportation industry, among others, to help guide the research and plan the most effective implementations—keeping researchers focused on how SHRP2 Solutions could be used in the field to maximize success. In support of developing implementable solutions, many agencies piloted the research results during the research phase to establish a proof of concept, identify which solutions were truly viable in the day-to-day world of transportation agency operations, and determine where further development was needed. Once full implementation began, the SHRP2 Solutions were deployed through seven rounds of the IAP. DOTs, MPOs, and other agencies in all 50 states participated in the gradual adoption of the solutions.

FHWA, AASHTO, and TRB have maintained a close, collaborative partnership throughout the entire SHRP2 research and implementation process. This strong partnership drove the success of SHRP2 implementation and established a model for the successful execution of programs and solutions.

A legacy of value

After more than five years of SHRP2 implementation, institutionalization of the SHRP2 Solutions is well underway. Many states—including those highlighted in this year's report—have expressed enthusiasm and

appreciation for specific products that have had marked impacts on the way they do business. Although several final IAP projects are still underway, many of the new tools and processes offered by SHRP2 have already taken root within agencies and, embraced by agency champions across the nation, have become fundamental to their day-to-day operations.

Like many of our nation's roadways, however, the path to success for SHRP2 is a lengthy one. While many of the earliest implementations have already shown positive outcomes, most implementation projects take five years or more to complete, so further study will be necessary to establish SHRP2's true long-term impact and value to agencies and the traveling public. In addition, work has begun to evaluate ten specific SHRP2 Solutions for their long-term impact, and preliminary results from this effort will be shared in next year's report. In the meantime, FHWA and AASHTO are talking to key state and local agencies about their overall experiences implementing SHRP2 products to get a better understanding of what their expectations were when they began using the products and whether those expectations were met or exceeded.

In parallel, FHWA is evaluating the program management aspects of SHRP2 implementation to assess how TRB, FHWA, and AASHTO planned, organized, established processes, and carried out SHRP2—from research through implementation. Interviews with key stakeholders and staff will provide information about successful practices and areas for improvement. This will reap both quantitative and qualitative data that can inform future nationwide transportation innovation deployment programs even as we change the path of that progress today.

SHRP2: Together we're moving forward and turning innovation into action.



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THE SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM

U.S. Department of Transportation Federal Highway Administration
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