

National Cooperative Highway Research Program

Fiscal Year 2018

April 2017

Announcement of Research Projects

The **National Cooperative Highway Research Program** (NCHRP) is supported on a continuing basis by funds from participating member departments of the American Association of State Highway and Transportation Officials (AASHTO), with the cooperation and support of the Federal Highway Administration, U.S. Department of Transportation. The NCHRP is administered by the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine. The NCHRP is an applied contract research program committed to providing practical and timely solutions to problems facing highway and transportation practitioners and administrators.

Each year, AASHTO refers a research program to the TRB consisting of high-priority problems for which solutions are required by the states. The NCHRP program for FY 2018 is expected to include 22 continuations and 35 new projects.

This announcement contains preliminary descriptions of only those new projects expected to be advertised for competitive proposals. **Detailed Requests for Proposals for these new projects will be developed beginning in July 2017.**

Please note that NCHRP requests for proposals are available only on the TRB website. Those who have an interest in receiving RFPs can register on the website <http://trb.org/nchrp>.

Upon registration, you will receive an e-mail notification of every RFP posting and an e-mail notification of new anticipated projects in future years.

Because NCHRP projects seek practical remedies for operational problems, it is emphasized that proposals should demonstrate strong capability gained through extensive successful experiences in the relevant problem area. Consequently, any agency interested in submitting a proposal should first make a thorough self-appraisal to determine whether it possesses the capability and experience necessary to ensure successful completion of the project. The specifications for preparing proposals are set forth in the brochure entitled [*Information and Instructions for Preparing Proposals*](#). **Proposals will be rejected if they are not prepared in strict conformance with the section entitled “Instructions for Preparing and Submitting Proposals.”** The brochure is available on the Internet at the website referenced above.

Address inquiries to:

Lori L. Sundstrom

Manager

National Cooperative Highway Research Program

Transportation Research Board

lsundstrom@nas.edu

IMPORTANT NOTICE

Potential proposers should understand clearly that the research program described herein is tentative. The final program will depend on the level of funding available from the Federal-aid apportionments for FY 2018. Meanwhile, to ensure that research contracts can be executed as soon as possible after the beginning of the fiscal year, the NCHRP is proceeding with the customary sequence of events through the point of research agency selection for all projects. The first round of detailed Requests for Proposals will be available starting in July 2017; proposals will be due beginning in September 2017, and research agency selections will be made in November and December 2017. This places the risk of incurring proposal costs at the election of the research agencies. Beyond the point of selecting agencies, all activity relative to the FY 2018 program will cease until the funding authorization is known. These circumstances of uncertainty are beyond NCHRP control and are covered here so that potential proposers will be aware of the risk inherent in electing to propose on tentative projects.



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**National Cooperative Highway Research Program
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SUMMARY OF APPROVED RESEARCH PROJECTS

◆ Project 01-59

Including the Effects of Shrink/Swell and Frost Heave in Mechanistic-Empirical Pavement Design

Research Field: Design
Source: AASHTO Joint Technical Committee on Pavements
Allocation: \$500,000
NCHRP Staff: Amir N. Hanna

Shrink/swell of expansive clay soils affects pavements from the Gulf of Mexico to the Canadian border including Texas, Oklahoma, Colorado, Arkansas, Louisiana, Mississippi, Alabama, New Mexico, Montana, North Dakota, and South Dakota. These states have significant montmorillonite clay minerals and evapotranspiration may exceed precipitation. The impact of the shrink/swell behavior is differential changes in moisture and vertical elevation from the center of the pavement to the paved edge. This variation results in increased pavement roughness over time.

For states in the northern half of the country, frost heave may also significantly affect pavement smoothness, especially when silty soils are present. In these areas, the freezing boundary will extend into the subgrade soils. Moisture will accumulate and freeze into “frost lenses.” As long as the subgrade remains frozen, the roadway is able to carry heavy loads. When the lenses thaw in the spring, the liquid water flows downward, leaving a void where the lens existed. The void collapses, causing a pavement failure that extends through the full depth of pavement structure. The frost heave issue affects ride quality in at least 15 states along the northern tier, and may affect additional states at higher elevations or in years with unusually cold winters.

Currently in the AASHTO Pavement Mechanistic-Empirical (ME) Design program, frost heave and shrink/swell are empirically predicted from other climatic variables, including freezing index, average annual precipitation, soil plasticity index, and percent passing the number 200 sieve; all of which are used to develop a site factor term. This term, along with the initial IRI for each site and calculated pavement distresses are used to estimate the International Roughness Index (IRI) at time t . The development of improved shrink/swell and frost heave models will greatly enhance the MEPDG methodology.

The objectives of the research are to (1) Develop a new ME model or improve upon an existing ME model for predicting shrink/swell movement in expansive clay soils under pavements, (2) Develop a new ME model or improve upon an existing ME model for predicting movement of pavement from the formation and thawing of frost lenses, and (3) Harmonize the shrink/swell and frost heave models into a single model for predicting overall pavement smoothness deterioration.

◆ **Project 01-60**

Calibration and Verification of Pavement Surface Images

Research Field: Design
Source: AASHTO Joint Technical Committee on Pavements
Allocation: \$600,000
NCHRP Staff: Amir N. Hanna

The accuracy of existing data collection methodologies is not traceable or uniform. State highway agency (SHA) practitioners need a way to appropriately calibrate as well as to assess and verify the accuracy of image data collection systems.

With the growing use of imaging systems for conducting pavement evaluations, the industry continues to struggle with how to calibrate the imaging systems and verify that they are properly functioning as intended. While the AASHTO Provisional Standards have been created for collecting such imagery, there is still no widely accepted method for measuring the accuracy of such imagery.

The objectives of this research are to (1) Determine traceable, objective, practical, repeatable, and transparent methods and approaches to assess the accuracy of the system and the subsystem components by developing or identifying a methodology to calibrate the image data collection systems and subsystems, including (a) developing measures and approaches to assess the appropriateness and relevancy of such a calibration methodology, (b) developing appropriate measures and methods to determine the accuracy of the image data collection system, and (c) verifying the reliability of these measures and methods under actual conditions and (2) Develop a system level accuracy statement.

◆ **Project 01-61**

Performance Evaluation and Life Cycle Cost Analysis of Bonded Concrete Overlays on Asphalt or Composite Pavements and Development of Recommended Maintenance and Rehabilitation Procedures

Research Field: Design
Source: AASHTO Joint Technical Committee on Pavements
Allocation: \$500,000
NCHRP Staff: Edward T. Harrigan

Bonded concrete overlays on asphalt (BCOA) surfaces are a fast growing pavement preservation and rehabilitation treatment in the U.S. They have been demonstrated as effective solutions for correcting areas with excessive rutting and shoving caused by slow, heavy loads, such as at intersections. They have also been shown to be effective as a longer term overlay option on regular mainline pavement. To be economical, most BCOA projects consist of a concrete overlay thickness ranging from 3 to 7 inches, with corresponding smaller panels sizes ranging from 4 feet square to 12 feet square. Many projects have been constructed with a 6 feet square panel size that does not incorporate doweled joints. Some BCOA projects include the use of structural fibers in the concrete to enhance post cracking durability.

Major advancements have been made recently in the design theory for BCOAs. In 2013, a new mechanistic-empirical procedure titled “BCOA-ME” was developed at the University of Pittsburgh through a FHWA pooled fund study. While the design methods for BCOA have advanced, there still remains a national need for information related to optimal BCOA concrete mix designs, construction practices, and maintenance repairs, as well as a comprehensive review of overall performance. Current assumptions about anticipated design lives of BCOAs are derived from localized studies, and design lives are typically chosen as a maximum of 20 years. Variables impacting design life include the previous condition of the existing pavement structure, the time-dependent degree of bond between layers, overlay thickness, panel size, and traffic. Not only are typical design lives generally unknown, but the timing and types of maintenance and repair activities need further study and determination. Some agencies remain skeptical about using BCOAs because of perceived design deficiencies drawn from anecdotal information derived from earlier, mostly experimental BCOA sections which experienced early failures. There have now been enough non-experimental projects built that can be surveyed to determine the best construction practices, expected performance lives, and potential maintenance requirements.

The objectives of this research are to: (1) document the performance of a range of bonded concrete overlays on asphalt projects constructed throughout the U.S., (2) identify typical maintenance and repair techniques that successfully extend their lives, and (3) develop representative performance curves to aid in project selection, design, and life cycle cost analyses.

Note: In approving this project, the AASHTO Standing Committee on Research noted that currently in-service applications are approaching the end of useful life, so the research will provide timely assistance. Life-cycle cost information developed in the project will be useful to other agencies considering this design.

◆ **Project 03-128**

Business Intelligence for Transportation System Management and Operations and Agency Decision Making

Research Field: Traffic
Source: AASHTO Highway Subcommittee on Transportation Systems Management and Operations
Allocation: \$360,000
NCHRP Staff: B. Ray Derr

Business Intelligence (BI), as applied in the private sector, is an umbrella term that refers to the analysis of disparate raw data using data mining techniques, on-line analytical processing, querying, and reporting/visualization to make better business decisions. BI techniques are well suited to Transportation System Management and Operations (TSM&O) as it is a data-oriented function that attempts to optimize the multimodal operational performance of the highway and transportation networks through operational strategies as well as project-based transportation system improvements. TSM&O is driven by diverse data and information from an expanding number of public and private sector sources, such as:

- Data about traffic operations, environmental conditions, and infrastructure assets;
- Driver and shipper trips and demand patterns;
- Internal organizational resources and capabilities; and
- Budget considerations including financing needs.

Transportation agencies' TSM&O groups must integrate these data; generate relevant and timely information, knowledge, and intelligence; and incorporate the outcomes almost continuously into various agency and transportation system management decision-making processes. Some examples decisions that could be supported through applying BI data analysis and visualizations include:

- Determining active operational management and response strategies—including those involving traffic engineering and operations and highway maintenance,
- Establishing lifecycle financial investment strategies for operational programs and associated operations and ITS infrastructure systems based on data driven performance measures, and
- Addressing human resource allocation and asset management as well as corporate financial and budget management.

Applying BI practices using integrated transportation operations and asset management information has the potential to improve system performance management through enhanced decision making relative to agency goals and objectives. The traditional focus has been on active operation of the transportation system based on situational awareness of traffic and environmental conditions by providing guidance on immediately viable tactics to mitigate recurring congestion and non-recurring disruptions. However, managing transportation investments also requires asset and operational performance data and information that are dynamically integrated with financial data and budget information. In both operational management and investment management contexts, Business Intelligence practices and methods could be more effectively incorporated by transportation agencies, which could enable enhanced trade-off analysis and more effective enterprise resource planning.

Research is needed on ways to use BI in identifying the value of investment in multi-modal operational improvements and strategies, especially with respect to programs for major investments and state of good repair. Research is also needed on how BI practices can lead to a higher level of confidence in the effectiveness of TSM&O programs among policy makers and to reduce (and perhaps eventually eliminate) the need to have parallel tracks for funding consideration.

The objective of this research is to develop a report defining a BI framework of TSM&O program management decision-making process types and example applications that encompass operational management, infrastructure management, investment management, as well as organizational and corporate management. The research will assess current processes and analysis methods that are foundations for how core decision-making

processes occur: (1) within TSM&O programs, (2) in conjunction with associated and encompassing agency functions, and (3) in an integrated and supportive fashion by data and information associated with on-going operations. Significantly, the research will identify and consider how effective and emerging BI practices, models, or approaches from other industries can be applied to TSM&O and transportation agency program management processes. Particular attention will be paid to BI practices that reduce the cost of providing services or improves the quality and effectiveness of decision-making capabilities.

Project tasks are expected to: (1) Scan and synthesize current Business Intelligence best practices, technologies, and data analytics applications in the private sector and other industries and identify those that are potentially most applicable to TSM&O in nature, extent, and objectives; (2) Leverage TSM&O Capability Maturity Modeling (CMM) and other recent efforts to define and assess BI related business and decision-making processes within transportation agencies; (3) Incorporate findings of various private sector BI efforts that are recognizing the rapidly expanding sources, types, and overall quantity of relevant data; (4) Assess and define effective and emerging BI processes, methods, practices, tools, approaches and organizational models for the management and integration of these data into TSM&O decision-making processes. The development of case examples and a literature review can be used. The processes, methods, and performance management strategies should be developed so as to better demonstrate to policy makers the effectiveness of TSM&O programs; (5) Define a BI framework of TSM&O program management decision-making process types and example applications that encompass operational management, infrastructure management, investment management, organizational and corporate management, and others; and (6) Correlate data and data management characteristics, use cases, and needs to the framework.

◆ Project 03-129

Essential Communications

Research Field: Traffic
Source: AASHTO Special Committee on Transportation Security and Emergency Management,
AASHTO Special Committee on Wireless Communications Technology
Allocation: \$450,000
NCHRP Staff: Stephan A. Parker

The current systems used to communicate between transportation field elements, such as Road Weather Information Systems (RWIS), sensor networks, and Changeable Message Signs are dependent on leased services that may include cell phone technology, or private telephone lines. The leased services can be unreliable, and often times unavailable in rural, less traveled areas. Areas where the ability to communicate and gather travel information is critical field crews that increasingly base winter highway treatment decisions and traveler information on reliable communication systems. In addition to access challenges, there often are recurring costs associated with leased services, and these costs may hinder the addition of field elements required to adequately monitor a corridor or specific areas of a roadway. Many DOTs have invested heavily in radio communications systems to support their field staff during their daily activities and during incident response or emergencies. With the proper planning and design, the same communications system can be used to acquire and provide information from the field elements. Radio communications traditionally have a proven higher degree of system performance and reliability than leased services.

The proposed research will help DOTs leverage existing communications systems to acquire and provide reliable and timely information from field elements using the 700 MHz radio spectrum. Using that spectrum also may provide interoperability with the federally planned Nationwide Public Safety Broadband Network (NPSBN or FirstNet), which utilizes Band 14 (758-798 MHz). The NPSBN will provide data communications services, including video, to public safety providers throughout the nation. PSBN (FirstNet) will begin implementation in 2017. The start dates for each state will vary as some states are further ahead in the process than others. There is an “opt-out” option for each state—meaning states can deploy their own network in lieu of FirstNet, but approval from FirstNet is required.

700 MHz was selected for this potential research project for the following reasons:

- The FirstNet system will also be utilizing the 700 MHz band, and this will allow interoperability, and
- 700 MHz channels became available when cable TV (channels 60-69) converted to digital.

If a state has radio infrastructure on another radio band (150/450/800 MHz), they can leverage those assets instead of 700 MHz. The project also should determine how many states have access to a 700 MHz radio network and what the associated costs would be to connect to field devices. As part of this research, a proof-of-concept study will be performed with various field elements, providing information through a 700 MHz radio system. This capability also can be used as a backup to essential assets that may be impacted by the private leased services. Caltrans has an 800 MHz, 2-way land mobile radio installation along Hwy 199. The radio equipment is housed in a standard traffic cabinet, while the antennas and wind generation are on a 30-foot pole; a similar approach could be followed for the RWIS, or other field elements, where feasible.

If the radio communications platform is capable of providing the communications required by the field elements, State DOTs will achieve significant savings by eliminating leased service fees, and at the same time, operate a more reliable communications system. Communication systems are the backbone of emergency management and infrastructure protection coordination. These systems enhance resilience. This project can help with other AASHTO and TRB research efforts, such as FloodCast, FireCast, ShakeCast, and it can help to mainstream emergency notification systems as well.

◆ **Project 03-130**

Production of Roundabouts: An Informational Guide, Third Edition

Research Field: Traffic
Source: Oregon, Pennsylvania
Allocation: \$750,000
NCHRP Staff: Amir N. Hanna

The publication *NCHRP Report 672: Roundabouts: An Informational Guide, Second Edition*, published in 2010, serves as the definitive national guide for roundabout planning, analysis, and design in the United States. It has received broad use throughout the transportation profession. FHWA has adopted it as its official guidance on roundabouts, and many states have adopted it in total or in part as part of State standards, guidance, and advice for roundabouts. It has also been used around the world as one of the major international reference documents on roundabouts. A Third Edition needs to be produced for three major reasons:

1. Since the publication of the Second Edition in 2010, at least 37 major research reports and guidance documents have been produced, reflecting the broad interest in roundabouts at the Federal, State, and local levels. Many of these research reports are the product of funded research from AASHTO and FHWA. Each of these documents reflects advancement of practices in planning, performance assessment, design, and implementation. These advancements now need to be reflected in an updated Guide to have this wealth of new, updated material in one easily accessible and widely accepted document.
2. The Guide is directly referenced in the AASHTO Policy on Geometric Design of Highways and Streets, as well as many State roadway and facility design manuals. It is important that it contain current and up-to-date information regarding planning, performance assessment, and design practices.
3. The TRB Committee on Roundabouts (ANB75) has identified research gaps in the material covered in the Second Edition Guide (2010 edition) that have not been covered in the aforementioned research projects or were identified in those projects as continuing research needs. A set of these are anticipated to be of the scale and scope to be included in this edition.

The objective of this research is to develop a Third Edition of *Roundabouts: An Informational Guide* by updating the current guide and addressing identified gaps in previous design knowledge with the latest information and practices developed since publication of the Second Edition of *Roundabouts: An Informational Guide* in 2010. This objective should be met through two major tasks: (1) Prioritize gaps in research knowledge and conduct targeted research to fill those gaps. These may include (a) Guidance on design options for accommodating oversize/overweight (OSOW) vehicles and (b) Updated guidance on the use of traffic control devices at roundabouts, suitable for consideration by FHWA and the National Committee on Uniform Traffic Control Devices (NCUTCD) for the next edition of the MUTCD, and (c) Guidance for design of tactile wayfinding surfaces on sidewalks to aid pedestrians with vision disabilities in locating the crosswalk and aligning to cross as identified by the TRB Committee on Roundabouts; and (2) Prepare an updated Third Edition that incorporates research conducted and best practices developed since the Second Edition.

◆ Project 03-131

Benefits and Best Practices in Implementing Decision Support Systems for Real-time Transportation Management

Research Field: Traffic
Source: AASHTO Highway Subcommittee on Transportation Systems Management and Operations, Virginia, Georgia
Allocation: \$750,000
NCHRP Staff: B. Ray Derr

Recent initiatives in the U.S., Asia, and Europe have pointed to the potential benefits of using real-time simulation models and performance measure techniques for enhancement and operation of Decision Support Systems (DSS) for use in Integrated Corridor Management (ICM).

The real time analytics required for ICM go far beyond what is typically required for more traditional types of transportation operations where single network management is the focus. An emerging analytical tool is a Real-Time, Multimodal Decision Support System (RTMDSS). These systems are information systems that support multimodal, transportation operational decision-making in real-time. An RTMDSS is an interactive, software-intensive system that gathers data from multiple relevant real-time data sources and knowledge bases. It uses these data, along with models, processes or analyses to implement context-specific actions and recommendations to assist managers in the process of collaboratively managing a multimodal transportation network to increase system efficiency and improve individual mobility, providing safe, reliable, and secure movement of goods and people. A recent USDOT project assessed the emerging opportunities for RTMDSS in transportation operations and developed a generic concept of operations for a RTMDSS.

A recent NCHRP Domestic Scan team reviewed the implementation of ICM across the U.S. The Scan Team Report reviews various ICM deployments, including an analysis of real-time models for planning and operations for ICM, and the implementation of DSS for ICM. As part of the final report, an ICM Capability Maturity Model (CMM) was developed which covers six process areas for ICM, including DSS.

The objective of this research is to develop guidance on the planning, design, deployment and on-going operations of a real-time DSS and simulation based on the user needs of the regions implementing ICM. The guidance will include: (1) a comprehensive report of existing studies and data on operational impacts of real-time simulation and DSS for use ICM with focus areas on data fusion, prediction, simulation, approaches to event response, and institutional coordination; and (2) a guidebook on ICM DSS and simulation for regions, including data needs, methodologies, and benefits.

This research will require the following tasks:

Task 1. Literature Review. Conduct a comprehensive survey (literature review, surveys, interviews, etc.) of existing studies and data on use of simulation in Decision Support Systems for ICM and Smart City initiatives in the U.S. and abroad, and more broadly on the use of DSS in Transportation Systems Management and Operations (TSM&O) related topics. The synthesis will also cover the corresponding lifecycle costs, human resource demands and skills required, and institutional and management challenges with operating and maintaining a DSS.

Task 2. Summary Report. Develop a comprehensive summary report of existing studies and data on operational impacts and costs, resource requirements, and challenges of operating and maintaining a DSS and real-time simulation model.

Task 3. Enhancement and Data Collection Plan. Develop an overall Methodology Enhancement Plan and Data Collection Plan for the effort needed to validate, test, and expand the current understanding and capabilities of real-time simulation for DSS for an ICM implementation. The plans can be organized along four focus areas, namely (A) institutional coordination, (B) real-time data and performance measurement, (C) modeling and traveler behavior, and (D) staffing needs. The research topics presented here are based on gaps and needs identified in the ICM process. They can be reduced or expanded based on needs by others, funding availability, criticality of mission among others.

- Focus Area A, Institutional Coordination. There must be open communication and cooperation among agencies to operate the assets within an integrated corridor. This can be done informally (i.e., operational personnel share information and coordinate responses among agencies) or more formally (i.e., through intergovernmental agreements or MOUs that define roles and responsibilities). Some areas have been successful using high-level ITS cooperative MOUs, while others have developed ICM-specific MOUs. The following institutional challenges are of particular interest: changes in maintenance practices (particularly, quick replacement of defective data collection equipment and installation and testing standards for sensor equipment); institutional arrangements and approaches for successful system management; changes in planning practices to focus on non-recurrent congestion and real-time traffic management; and operational organization models for ICM and DSS, including recommended language for MOUs.
- Focus Area B, Real-time Data and Performance Management. Data needs and standards for performance measures and performance management are critical for DSS and simulation models for ICM. Potential topics to cover in this focus area include: detector layout optimal monitoring and identification of traffic patterns, data collection technologies and sources, data fusion of multiple data sources (including public and private data), risk analysis on the impact of equipment failure (including detectors, communications devices and systems, hardware, software, agency communication), data exchange protocols and data standards, data filtering, techniques to address data gaps and missing data, and standardization of performance measures (for operators, decision-makers, and travelers), multiple objective decision making (e.g., mobility improvement, emissions reduction, emergency vehicle access and response time), and the incorporation of big data (including changes in the capability and the demand for performance management).
- Focus Area C, Modeling and Traveler Behavior. This task will look at the model requirements for simulation and compare the various DSS software platforms to include real-time simulation. Potential topics to cover include: need for a hybrid solution between analytic (model-based) DSS and artificial intelligence-based DSS; development of time-dependent origin-destination patterns in real-time; automation of real-time calibration and DSS self-learning; comparative review of strengths and weaknesses of existing DSS software platforms; inclusion of dynamic multimodality in real-time using a unified cost function across highway and transit; impacts of ICM on travel behavior (including mode shift, route diversion, temporal shift); key decision variables (e.g., values of time, travel time reliability); and provision of information to travelers.
- Focus Area D, Staffing Needs. The creation of a DSS potentially requires new skill sets and training for the development and ongoing operation and maintenance of a DSS. Information on the knowledge, skills, and abilities (KSA) and relevant training needs for a successful implementation and ongoing operation of the ICM/DSS will be needed.

Task 4. Data Collection. Perform data collection following the approach detailed in the Data Collection Plan developed in Tasks 3-6. Data shall be cleaned, organized, and documented in a form suitable to proceed with Task 5.

Task 5. Conduct Research. Develop methodologies following the approach detailed in the Methodology Enhancement Plan developed in Tasks 3. Demonstrate the data collected and methodology improvements in a simulated environment, and produce estimates of additional benefits resulting from the improved methods and data.

Task 6. Knowledge Transfer. Make best practices, data and methodologies available to the transportation community. Develop an ICM and DSS Guidance Document on the key items and best practices to consider when implementing a DSS for Transportation Management and ICM. This would build upon the ICM Implementation Guide, developed by USDOT for the ICM program – but look specifically at the DSS and simulation aspects of ICM.

Note: The AASHTO Standing Committee on Research directed that the deliverables should go beyond a guidebook to provide material that is useful to agencies in developing and deploying DSS. Customizable systems engineering documents should be valuable. Software can be problematic and development should only be pursued if issues related to its development, implementation, and support can be resolved.

◆ **Project 03-132**

Improving the Safety and Efficiency of Temporary Traffic Control for Mobile Operations on Two-Lane Roadways

Research Field: Traffic
Source: Florida
Allocation: \$300,000
NCHRP Staff: William C. Rogers

Mobile operations on two-lane two-way roadways present unique problems due to highly variable conditions which are encountered in the field. Variables include the number of vehicles in the work convoy, travel speed of work vehicles, posted speed, roadway geometrics, and average daily traffic on the roadway. Highway agencies are challenged with developing temporary traffic management control (TTC) standards that ensure safe and efficient operations under these highly variable conditions, and consider the safety and mobility of road users.

Workers face many hazards during mobile operations on two-lane roadways. Many of these hazards are a direct result of the fact that motorists do not know how to properly react when encountering a work convoy. Examples of problematic motorist behavior include misunderstanding of traffic control devices, impatience with the delay caused by the slower speed of the mobile operation, inattention, speeding, and entering the convoy.

Temporary traffic control for most mobile operations has been limited to arrow panels and static warning signs mounted on the back of work vehicles. These devices often do not convey sufficient information to the motorist for them to make informed decisions. The truck mounted changeable message sign (TMCMS) is a technology that can improve driver understanding of specific hazards and desired responses to various mobile operations.

TTC for most mobile operations (as shown in Typical Application 17 in MUTCD Figure 6H-17) has historically been limited to a shadow vehicle with an arrow board in caution mode and/or a static sign with legend appropriate for the type of work. These devices often do not convey sufficient information for motorists to make informed decisions (such as when and if it is safe to pass the convoy). There is a need to enhance communication with motorists and provide more positive control of traffic in both directions during mobile operations on two-lane roadways. It is likely that this could be accomplished with the addition of flaggers at each end of the mobile operation to provide periodic passing opportunities for motorists.

Some state departments of transportation have developed enhanced motorist information systems for mobile operations on two-lane roadways. Wyoming DOT uses truck-mounted changeable message signs to relay information about the type of operation and the number of work vehicles involved. Texas DOT uses static CW21-10T signs to communicate how many work vehicles are in the operation. Research sponsored by Texas DOT investigated the use of truck-mounted changeable message signs to communicate information related to passing the work vehicles (i.e., DO NOT PASS, PASS WITH CARE, PASS ON SHOULDER, etc.) but ultimately found that implementation would be difficult because of constantly changing conditions that are inherent to mobile operations. In addition, it would be unwise to grant motorists permission to pass the convoy via changeable messages without fully controlling traffic coming from the opposite direction in the open lane. Other research sponsored by California DOT found that work zone intrusion crashes were caused by motorists entering the convoy (25%); rear-end crashes with a slower vehicle (25%); motorists striking work vehicle when passing (38%); and motorists swerving to avoid an adjacent crash (12%). The proposed research would address the issue of removing opportunities for motorists to make poor decisions by providing adequate opportunities for passing while controlling traffic in both directions.

The objective of this research is to develop TTC alternatives for mobile operations on two-lane roadways. Develop recommendations on communicating information to the motoring public in a manner that is well understood. The work zone devices used in the application should balance safety with the constant movement and/or stop-and-go nature of the work operation.

Possible research tasks may include the following:

1. Develop Work Plan
2. Summarize State-of-the-Practice
3. Develop TTC Alternatives
4. Evaluate TTC Alternatives
5. Develop Recommendations
6. Prepare Project Report

◆ Project 03-133

Signal Timing Strategies for Non-Motorized Users

Research Field: Traffic
Source: Oregon
Allocation: \$500,000
NCHRP Staff: Lori L. Sundstrom

Over the last decade, there has been increased interest in promoting active and sustainable transportation modes such as bicycling and walking, as a means to alleviate congestion, lower emission levels and improve personal health. Most of the walking and bicycling trips occur in urban areas, where signalized intersections are fairly common. The 2009 National Household Travel Survey (NHTS) estimated 42 billion walking trips per year, accounting for 10.9% of all trips undertaken. Additionally, bicycle trips increased from 0.7% of total trips in 1995 to 1.0% in 2009. Pedestrians often face unnecessary delays due to the traditional focus on prioritizing vehicular movements at signalized intersections. Additionally, most of the walking trips are short; a nationwide survey showed that 67% of walking trips are 1 mile or shorter in length. Because walking trips are shorter and signal timing is optimized for motor vehicles, delays at signalized intersections tend to affect pedestrians disproportionately compared to auto trips. Several studies have shown that delay is a key factor in pedestrian non-compliance. The *Highway Capacity Manual* (HCM) states that delays greater than 30 seconds are associated with increased frustration and risky behaviors. On the other hand, while bicycles are commonly served concurrently with vehicular movements, with the increasing number of cycle tracks co-located with roadways and the move towards protected intersection installations in specific locations, there is a need to focus on studying the efficiency of signal timing at locations with bicycle-specific infrastructure. There has only been a limited amount of research on this subject in the U.S.

Although the number of bicyclists and pedestrians is increasing, safety remains a top concern and can be a limiting factor in encouraging walking and especially in engaging new cyclists. According to National Highway Traffic Safety Administration, there were 4,884 pedestrian and 726 bicyclist fatalities and an estimated 65,000 and 50,000 pedestrian and bicyclist injuries in 2014 respectively. For both modes, majority of the fatalities occurred in urban areas, with 19% of pedestrian fatalities and 31% of bicyclist fatalities occurring at intersections. Pedestrian safety research at intersections has focused on lack of driver yielding, pedestrian non-compliance, and pedestrian visibility and the emergence of countermeasures such as countdown pedestrian signals, leading pedestrian intervals and exclusive pedestrian phasing. Given that bicycle traffic in the U.S. is typically served in the same lane as motor vehicle traffic or an immediately adjacent bicycle lane, much recent research has been focused on improving the safety of bicycles in the traffic stream. However, most of this research has focused on design treatments, with little to no research available on signal timing treatments for improving bicycle safety.

The goal of signal timing at an intersection should be to separate conflicting movements in time, maximizing safety and efficiency for all users. In many jurisdictions, however, signal timing objectives have traditionally focused on facilitating vehicle progression and reducing vehicular delay and stops. While these are important considerations in many contexts, other users, specifically bicycles and pedestrians, deserve similar focus and control strategies. Recent updates to the HCM have expanded modeling techniques for these users, but the overall approach remains largely vehicle-focused. Even when the analyst chooses to perform a multimodal analysis, very little guidance is provided for signal timing practices. Design guidance is available, but these focus on geometric treatments more than signal timing. The *Signal Timing Manual* outlines basic information on pedestrian and bicycle signal timing, but does not provide detailed information for selecting different timing strategies. In recent years, a few researchers have investigated specific topics within the larger scope of multimodal operation, but there has been no comprehensive development of a toolbox of timing strategies focused on improving the safety and efficiency of multimodal operations at signalized intersections. Similarly, there is considerable expectation of operational benefit from connected vehicles, but very little discussion of whether or how these technologies might impact non-motorized modes of traffic.

This research will help address the lack of guidance for signal timing strategies to better accommodate multimodal users. The main research outcome will be a guide for practitioners which integrates both novel signal retiming strategies (that have been proven to work well) and the findings of previous studies. An emphasis will be given to a comprehensive investigation of the efficiency and safety impacts of various multimodal treatments at conventional signalized intersections, but opportunities will be addressed for similar future studies on the intersections with multimodal specific infrastructure and intersections with alternative geometries such as DDIs, CFIs, and others.

Tasks anticipated in this project include the following:

- Review literature to identify deficiencies in current practice as well as the findings of research works attempting to address those deficiencies.
- Interface with City, County, and State transportation officials to identify traditional multimodal signal timing problems perceived by practitioners as well as those experienced when addressing these users at locations with multimodal specific infrastructure.
- Propose, test, and analyze various multimodal timing strategies at signalized intersections.
- Use video based conflict analysis and/or surrogate safety measures to identify safety impacts.
- Characterize the system components (level of detection, type of controller or controller software, type of communication system, etc.) necessary for successful deployment of these timing strategies. Identify levels of maintenance, support, and expertise a managing agency would need to make effective use of these strategies.
- Develop a tiered set of recommendations for agencies and agency personnel based upon the operational objectives of the agency and specific intersections to enable the effective use of the strategies developed within this work.
- Implement a set of recommendations developed in prior tasks in the field to allow for validation.
- Develop a set of recommendations scoped for assisting agencies across a spectrum of budget constraints and personnel capabilities to implement and utilize these timing strategies.

The work will help improve the safety and efficiency of vulnerable users at signalized intersections, something which historically not been the matter of focus. It will provide a suite of signal timing strategies and recommendations for agencies at various capability levels, and will cover a wide range of contexts ranging from isolated rural intersections to complex urban intersections that are members of an arterial or grid network. The research products will fill a void on guidance for multimodal signal timing that is urgently needed at a time when these travel modes are increasingly emphasized in street designs.

◆ **Project 05-23**

The Unintended Consequences of LED Roadway Lighting: Effects on Road User Health and Driver Alertness

Research Field: Traffic
Source: Virginia
Allocation: \$400,000
NCHRP Staff: Edward T. Harrigan

Light sources for roadway lighting are being converted from High Pressure Sodium (HPS) luminaires to Light Emitting Diode (LED) luminaires because they are energy efficient and offer better visibility. LEDs with higher (greater than 3000K) correlated color temperature (CCT) often have higher blue content in their spectrum (460 to 480 nm) than conventional High Pressure Sodium (HPS) lamps. Light in this wavelength affects the production of the hormone melatonin, which regulates the human circadian rhythm. Melatonin increases drowsiness, and it is naturally produced late in the evening until the early morning in humans. Recently, the American Medical Association (AMA) reported that roadway lighting with higher blue content such as the light produced by LEDs could adversely suppress melatonin and affect the sleep health of people (drivers, pedestrians etc.) exposed to it. However, a definitive link between melatonin suppression and roadway lighting has never been reported. Alternatively, there could also be an advantage of the blue content in the LEDs. Since the blue content in LEDs suppresses melatonin, it has the potential to reduce driver drowsiness and make them more alert. In order to design effective roadway lighting, research is needed to understand the relationship between melatonin suppression and driver drowsiness and health caused by LED roadway lighting. This research will lead to better lighting recommendations that will mitigate any harmful health effects of LED lighting while making drivers more alert.

The objective of this research is to evaluate the effect of the LED roadway lighting on the health and alertness of drivers. The research shall examine the main factors that may influence melatonin suppression in humans, viz., the strength of blue content in the light, the light level or intensity, and the dosage or duration of exposure. The strength of the blue content is dictated by the correlated color temperature (CCT) of the light sources. LED lights with CCTs greater than 3000K have stronger blue content than those below that threshold. It is also important to understand if the light levels experienced in nighttime roadway lighting influence melatonin suppression. Finally, the effect of duration of exposure or dosage on the suppression of melatonin shall be addressed. Understanding the role of dosage will help in determining limits of acceptable exposure to the roadway lighting. Dosage limits will also have important implications for adaptive lighting of roadways.

Note: In approving this project, the AASHTO Standing Committee on Research directed NCHRP to engage an expert from the NASEM Health and Medicine Division as a project panel member.

◆ **Project 05-24**

Guidelines for the Selection and Application of Vehicle and Equipment Warning Light Configurations, Colors, and Markings

Research Field: Traffic
Source: AASHTO Highway Subcommittee on Maintenance
Allocation: \$600,000
NCHRP Staff: Amir N. Hanna

In 2008, *NCHRP Report 624: Selection and Application of Warning Lights on Roadway Operations Equipment* presented guidelines for selection and application of warning lights to improve the conspicuity and recognizability of roadway operations equipment used for construction, maintenance, utility work, and other similar activities. To accomplish this objective, the researchers conducted a review of current practices for use of warning lights on maintenance vehicles and an investigation to evaluate several aspects of the warning light system. This investigation included photometric characterization, screening, and performance experiments to evaluate lighting parameters that influence system performance as defined in terms of glare and vehicle detectability.

This research project enhances *NCHRP Report 624* and does not replace it. Since *NCHRP Report 624* was completed, significant technology changes and pressure from increased speeds, traffic volumes, and distracted drivers necessitate additional guidelines to include: (1) the significant improvements made to light emitting diodes (LED) electronics and optics, which are replacing previous lighting technology; (2) on-road vehicle and off-road equipment configurations; (3) an evaluation and recommendation(s) for vehicle base color or combination of color; (4) minimum and maximum lighting configurations, using Class 1 lights (lighting; color and combination of colors, lens color; flash pattern, flash rate, and light synchronization; light synchronization between multiple vehicles; light placement; and light size and type); (5) combination of lighting systems with dissimilar characteristics; (6) minimum and maximum conspicuity configurations (pattern, colors, retro reflectivity sheeting type, and location and size); (7) urban and rural environments; (8) day, night, dusk, dawn, snow, rain, fog and other weather effects on lighting and marking recommendations; (9) rear, side, and front approaches to vehicles taking into consideration horizontal and vertical curves and oblique approaches; (10) interrelated effects of vehicle color, light color, combination of lighting systems, flash rate, and markings; and (11) effects of warning lights on traffic signs and message boards (in particular portable message boards), especially with older drivers.

The objective of this research is to update and enhance previous guidelines addressed in *NCHRP Report 624*. The research project will include on-road vehicle and off-road equipment configurations. This research will identify configurations and provide a tool that describes the interrelated effects of vehicle color, light color, combination of lighting systems, flash rate, and markings, with maximum and minimum limits, to make highway vehicles and equipment quickly and easily recognizable. This research project will build on the existing research done on warning lights, reflective sheeting, and base color with the intention to provide an all-embracing guideline for DOT vehicles. Results of this project will allow motorists the opportunity to better perceive hazards with highway maintenance and construction operations, reducing crash rates, and increasing safety.

◆ **Project 08-113**

Effective Transportation Asset Management Practices at State DOTs, Regional Organizations, and Local Agencies

Research Field: Transportation Planning
Source: AASHTO Planning Subcommittee on Asset Management, AASHTO Standing Committee on Performance Management
Allocation: \$540,000
NCHRP Staff: Lawrence D. Goldstein

The AASHTO Subcommittee on Asset Management is seeking to implement the Transportation Asset Management (TAM) Research Roadmap that was developed under the NCHRP 08-36 quick response research program and is available at <http://tam.transportation.org>. The TAM Research Roadmap was developed in cooperation with AASHTO, TRB, USDOT and other industry partners. It includes a multiyear research program that aims to improve the overall implementation of TAM at state, regional, and local transportation agencies. The purpose of the TAM Research Roadmap is to enable the TAM community to identify, develop and propose TAM research projects that are necessary to improve the understanding of TAM and allow for these projects to be funded through various research programs including NCHRP, quick response research funds (e.g., NCHRP Project 08-36), USDOT funding sources, etc.

The objectives of this NCHRP project will be two-fold: (1) To conduct TAM-related research to address those high priority issues identified by the industry through the TAM Research Roadmap; and (2) to conduct related technology transfer and information exchange activities. To be addressed are three separate smaller-scale research tasks that are closely related:

1. Best practices for Integrating Performance Management, Risk Management and Asset Management at Transportation Agencies;
2. A Comparison of TAM Frameworks with Case Studies of Implementation by Transportation Agencies; and
3. How to Recruit, Train, and Retain a Transportation Asset Management Staff

The AASHTO Subcommittee on Asset Management, a joint subcommittee of the Standing Committees on Highways and Planning, serves as the technical and policy resource on TAM issues for AASHTO. As such, the subcommittee frequently identifies needs for research to answer questions or develop methods for AASHTO member departments and individual transportation asset management professionals related to life cycle cost analysis, data collection, analysis, target setting, reporting and communication. This research will assist the Subcommittee on Asset Management in fulfilling its commitment, and AASHTO responsibilities, by helping to implement the TAM Research Roadmap.

The target audience for the research findings and products of this work will be state DOTs, metropolitan planning organizations, and other transportation agencies. The key decision-makers who can approve, influence, or champion implementation of these research products are the senior staff and CEOs of the transportation agencies. The AASHTO committees that will be involved in the adoption and implementation of the results will be the AASHTO Standing Committees on Planning and Performance Management and the Subcommittee on Asset Management will be responsible for the adoption of the results.

◆ **Project 08-114**

Guidebook for Estimating Contract Time and Evaluating Accuracy

Research Field: Transportation Planning
Source: South Dakota
Allocation: \$500,000
NCHRP Staff: Andrew C. Lemer

Establishing contract time is an important part of the highway project development process as contract time plays a significant role in determining the overall construction cost of a project, with more aggressive completion deadlines tending to increase construction costs. Extended completion dates result in longer periods of inconvenience for the traveling public due to longer periods of road construction. FHWA requires states to have a formal procedure for estimating contract time for highway construction projects and provides some recommendations for how contract times should be estimated. However, the accuracy of these tools has not been extensively examined in most agencies. A recent survey of state transportation agencies (STAs) with 41 STA respondents found that 68% of the respondents had formal, documented procedures using various methods for estimating contract time for projects but of that population over 50% did not formally evaluate their procedures or system for producing the contract time estimate. Research is needed to give STAs guidance regarding the value of having accurate and replicable processes for estimating contract time, a framework for strategically applying various contract time-estimate techniques appropriate to project characteristics and risks (including projects utilizing alternative delivery methods), and methods for evaluating time-estimation techniques and identifying how improvements may be made.

The objective of this research is to develop a guidebook that STAs can use to establish and maintain a systematic approach to estimating contract time through the application of estimation methods appropriate to project characteristics and risk, considering method accuracy and ways that accuracy may be improved. The guidebook should address conventional and alternative contracting methods.

The research should build on the findings of *NCHRP Synthesis 502: Practices for Establishing Contract Completion Dates for Highway Projects*, and may entail (1) updated review of the state-of-the-practice for contract-time estimation and methods for evaluating time-estimate accuracy, (2) identification and in-depth analysis of cases illustrating effective practices of agencies estimating contract time and considering the accuracy of estimates, (3) developing a preliminary guidebook on project-time estimation and related training materials to support an agency's adoption of the guidance, (4) conducting a workshop of representative users to validate and refine the guidance and training materials, and (5) production of a final guidebook and training materials. The guidance provided will assist the efforts of such groups as AASHTO's Standing Committee on Highways and Subcommittee on Construction to advance contract-time estimation practices across STAs and assist their development of more accurate contract-time estimation tools.

◆ Project 08-115

Framework for Designing and Managing Data and Information Workflows for Transportation Assets

Research Field: Transportation Planning
Source: AASHTO Highway Subcommittee on Construction
Allocation: \$450,000
NCHRP Staff: Andrew C. Lemer

The rapid growth of information technologies has changed the way state highway agencies produce, exchange, and manage the project data throughout the life cycle of a transportation project. The adoption of various advanced digital technologies has enabled a large portion of the project data to become available in digital format. However, due to the fragmented nature of highway project delivery processes, data sets are archived and managed separately. The current practices do not allow transportation assets to benefit fully from the growing amount of digital data since data created by project participants are not yet fully linked and available for reuse.

Organizing and maintaining data and information throughout the project development and asset management stages is a challenging task but has a significant impact on the decision-making process. Through seamless exchange of data and information throughout the project life cycle, a significant amount of data recreation can be minimized and high efficiency in business decision making can be achieved. Consistency in data collection, storage, sharing, and updating over time is also the key to improving the effectiveness and efficiency of project delivery and asset management. However, there is a lack of the consistency in data flow in almost all state DOTs. The consistency issue of data flow occurs in a single project, multiple projects (program level), geographical locations, and across time. Achieving seamless exchange of data and information will directly meet the goal of FHWA EDC Program Initiatives 3 and 4, which focuses on better, faster, and smarter ways of delivering transportation projects through integrating the use of information technology and collaboration.

Data standards along with process standards also need to be developed in collaboration with information technology experts, and project participants. For example, Virginia DOT has spent 2 years to establish a database from various stakeholders such as data analysts, ecologists, project participants, and others. As a result, more than 120 documents were reviewed and updated and the structure of metadata was defined. Iowa DOT and Connecticut DOT are currently working to understand data workflows for different types of assets and develop effective data flow processes using various software programs. Cloud-based computing and data warehousing also offer significant opportunities for enhanced collaboration and access to project information. Research is needed to address these issues and provide agencies with guidance on effective practices for managing transportation asset data and information workflows.

The objective of this research is to identify effective practices for managing integrated data and information workflow, including processes for documenting, organizing, exchanging, and managing data throughout the project development process. The research should develop a framework that can be used by transportation agencies to modernize their data management practices at both project and program levels. The framework should include actions for designing and streamlining data and information workflows across entities, phases, locations, project types, and time to help agencies develop common platforms and effective reporting tools supporting data-driven decision making in delivery of transportation projects and programs.

The research may entail tasks such as the following: (1) review and synthesis of relevant literature, research findings, and other appropriate material, inside and outside of the transportation industry; (2) identification of state-of-the-practice benchmarks to characterize transportation agency data organization and management practices; (3) development of a framework that agencies can use in customizing their business practices concerning collection, storage, sharing, and updating data; (4) documentation of a representative set of case-study transportation projects illustrating effective data management practices and issues involved in setting up and maintaining those practices; and (5) development of guidance for agencies to establish, improve, and maintain effective data and information management practices.

◆ **Project 08-116**

Framework for CV Pilot and Smart Cities Data Analytics for Policy Guidance

Research Field: Special Projects
Source: NCHRP Project 20-113
Allocation: \$400,000
NCHRP Staff: Lawrence D. Goldstein

The expanding deployment of emerging technologies such as connected vehicles (CVs), automated vehicles, shared mobility, and smart cities and communities, has increased demand for application of relatively new testing and implementing methods, encompassing field operational tests (FOTs), trials, and model deployments. Such methods entail extensive data collection from real users operating on public roads. While the databases previously developed have been curated and analyzed for specific project purposes, broad collaboration has not yet occurred for the purpose of informing state and local agencies of lessons learned and best practices in deployment.

The range of such deployments has recently expanded to include U.S.DOT's CV Pilot Deployment Program, the Smart City Challenge, and the Advanced Transportation and Congestion Management Technologies Deployment program of FHWA. These programs are convening collaborative actions that include AASHTO's Vehicle-to-Infrastructure Deployment Coalition, the CV Pilots Technical Roundtable, and AASHTO's Signal Phase & Timing Challenge. These leading-edge activities are addressing technical challenges to deployment, including cybersecurity; however, there is a residual need for collaborative data analytics to address a large number of policy questions of relevance to a broad range of state and local public agencies.

It is generally agreed that the coming decade will see rapid changes in transportation, and state and local transportation agencies are eager to benefit from the experiences of early adopters. The NHTSA Notice of Proposed Rule Making for vehicle-to-vehicle communication provides definite time frames for wide deployment of connected vehicle technology. Further expansion of CV and smart cities pilots is assured, and the proposed framework for data analytics will help streamline these deployments.

The objective of this research is to develop a framework for aggregating data from CV pilot deployments and smart city initiatives to assist in the development of guidance for transportation policy. The CV information aggregation framework needs to take into account the full range of policy questions relevant to agencies at the state and local levels, as affected by policies at the federal level. The framework needs to include a taxonomy of data collection activities and a generally applicable data curation model. The ability of this data model to address the range of policy questions needs to be considered, and gaps need to be identified. Finally, a comprehensive, prioritized set of accelerated, dynamic research projects, using the data to address suites of policy issues, needs to be developed and documented. Pilot deployments are well under way and are expected to proliferate. Agencies will benefit greatly from the lessons learned, particularly as these lessons improve efforts to increase portability of the information.

◆ **Project 08-117**

Impact of Transformational Technologies on Land Uses

Research Field: Special Projects
Source: NCHRP Project 20-113
Allocation: \$200,000
NCHRP Staff: Andrew C. Lemer

Several transformational technologies are coming together to profoundly influence transportation in cities and the broader impact of transportation on city services and operations. These beneficial technologies include mobility-on-demand (MODs) services, shared vehicles, connected and automated vehicles (CAVs), alternative-fuel vehicles (AFVs), smart cities and communities, and big data analytics. Further impact is anticipated from unmanned aerial systems, internet-of-things, and 3D printing. As MOD services have developed and proliferated in recent years (including transportation network companies [TNCs] such as Uber and Lyft), freight mobility is being affected as well personal transportation. Some of the initiatives and impacts are concentrated in identifiable corridors and precincts; others are more diffuse across urban, suburban, and rural space.

Very little information is currently available on the impacts of these technologies or their implications for government operations and finances. Tools to assist planners considering the implications of technological change are not available. The lack of information as well as the rapid rate of technological change pose challenges for policy makers at the local, regional, and state levels. For example, changes in how the “last mile” of retail (getting the goods to the consumer) is traversed are visible in real estate markets for “brick and mortar” retail stores and distribution-center facilities. MOD services and TNCs, in partnership or competition with more traditional public transportation services, appear to be influencing demand for transit-oriented development.

As these transformational technologies continue to evolve and spread through the economy, other impacts on land use will likely be felt. Some observers suggest that CAVs and shared vehicles will reduce—perhaps dramatically—demand for parking, in turn making significant amounts of urban and suburban land available for other purposes. Others suggest that automation of trucks and changes in freight transport operations will affect the location, function and layout of freight transfer facilities. Development of “smart corridors” with improved safety and efficiency of heavy truck operations could attract commercial activity and encourage changes in land use. Research is needed to explore how transformational technologies may influence future land use and describe plausible scenarios of future land-use patterns to inform transportation planners and policy makers in agencies that will be called on to ensure that our transportation system continues to provide effective, efficient, safe, and environmentally friendly access and mobility.

The objective of this research is to document potential and likely changes in site selection and demand for retail, office, distribution, production, housing, and parking land due to development of transformational technologies. The research should give broad consideration to transformational technologies, but may focus on three to five technologies likely to be particularly influential over a period of one to two decades. The research should consider implications for urban development patterns as well as real estate markets and issues of government policy as related to personal travel and freight transportation. The products of this research should be useful to government agencies and other stakeholders in local and state government responsible for infrastructure investment and land use and community planning.

◆ **Project 10-101**

Examining State DOT and USDOT Construction Cost Inflation Indices and Methods

Research Field: Materials and Construction
Source: South Dakota
Allocation: \$250,000
NCHRP Staff: Lori L. Sundstrom

State DOTs and the USDOT use different approaches to estimate construction cost inflation. There may be very good reasons to have different approaches:

- Construction materials and service costs vary by state and so do the items tracked and used in cost inflation calculations.
- The National Highway Construction Cost Index (NHCCI) depicts construction cost inflation to be relatively flat, but many states have a different experience.
- Some agencies calculate inflation rates for specific materials, geographic regions, or project types.
- Appropriate short-term and long-term inflation rates generally differ.

To expand the knowledge that state DOTs possess and to improve state practices in estimating construction cost inflation, it would be valuable to survey the states and try to understand the different, innovative, and effective approaches and their outputs. Findings would aid states in improving construction cost inflation and cost estimation practices.

Many research studies have mentioned construction cost inflation but few have addressed it as a key issue affecting construction cost prediction and construction cost estimation for purposes of bid-letting, fiscal constraint, developing Statewide Transportation Improvement Plans and Transportation Improvement Plans, and long-range planning.

The primary objective of this research is to analyze if particular state construction cost inflation practices are more successful than others along with the National Highway Construction Cost Index and determine if some of the approaches may be transferrable to other states.

Potential tasks may include (1) surveying states to determine the various approaches used to estimate construction cost inflation; (2) describing various state construction inflation estimation practices and the NHCCI; (3) determining if some of the approaches are more successful than others in estimating future construction cost inflation, and analyzing and describing why that is the case; (4) describing effective practices for estimating construction cost inflation; and (5) comparing the construction cost inflation rates estimated by states and the NHCCI to actual cost outcomes.

◆ **Project 12-114**

Benchmarking Study of Software for One-Dimensional, Nonlinear Seismic Site Response Analysis with Pore Water Pressure Generation

Research Field: Design
Source: AASHTO Highway Subcommittee on Bridges and Structures
Allocation: \$750,000
NCHRP Staff: Waseem Dekelbab

The primary concern over the applicability of equivalent linear site response analyses is due to the pore water pressure generation and dissipation that accompanies cyclic loading of saturated soils. If the generated pore water pressures are sufficiently large, soil stiffness and strength are significantly reduced. Ultimately, in some soils, liquefaction can occur due to this pore pressure generation. These phenomena are not captured by equivalent linear analysis. In a nonlinear site response analysis with pore water pressure generation and dissipation, response of soil to cyclic loading accounts for generation of excess pore water pressure during cyclic shearing of the soil as well as dissipation of these excess pore water pressures during and after the cyclic loading. The generation, dissipation, and redistribution of pore water pressure influences the soil stiffness (modulus) and strength (shear stress) during shaking, resulting in a more realistic simulation of site response if these effects are captured properly. However, no comprehensive benchmarking study has been performed for nonlinear effective stress analyses with pore pressure generation, and no design guidance on the use of these types of analysis is available.

The objectives of this research are to: (1) develop a better understanding of the input parameters required for 1-D nonlinear site response analyses, with pore water pressure generation; (2) perform rigorous benchmarking of available software that validates those models; and (3) provide guidance to designers on the use of these models.

◆ **Project 13-07**

Guidelines to Calculate Total Cost of Ownership for Fleet Operations

Research Field: Maintenance
Source: AASHTO Highway Subcommittee on Maintenance
Allocation: \$300,000
NCHRP Staff: Andrew C. Lemer

The equipment fleet is a major financial investment for a state DOT and is crucial to the agency's efforts to ensure the mobility and access essential to the state's economy and quality of life. The effectiveness of the equipment fleet operations affects the DOT's ability to perform routine activities efficiently and effectively and to respond successfully to emergency events. Equipment acquisition and costs of labor, parts, and fuel for preventive maintenance (PM) and repair now consume up to 30 percent of a DOT's infrastructure maintenance dollars. Total annual equipment-related expenditures may approach \$80M in a typical DOT.

Appropriate fleet asset management will result in substantial savings and make available valuable fiscal resources for other uses. Moreover, the productivity and safety of work crews and personnel depends upon their having the correct equipment available when needed to support and successfully accomplish work activities.

Knowledge and understanding of all fleet cost elements and accurate allocation of costs are critical to at least three important aspects of a DOT's fiscal management: (1) cost estimating for budgeting, procurement, and asset management; (2) agency performance management and evaluation; and (3) fiscal budgeting, cost control, and financial and other decision making. DOTs need accurate, reliable, and generally acceptable methods for determining and reporting their total costs of ownership for their mobile equipment (including acquisition, depreciation, rental, operation, insurance, fueling, PM and repair, mobile servicing, storage, garaging, and more). Research is needed to identify all cost elements of fleet operations and develop effective methods for collecting and using cost data to support full understanding of all direct and indirect fleet operations costs.

The objective of this research is to develop a methodology and provide guidance for DOTs to use in characterizing and assessing the vehicle fleet total cost of ownership. The research results will inform fleet customers (both internal and external, such as elected officials and road users) as well as fleet-services providers and senior agency decision makers. The research may entail such tasks as developing a synthesis of current literature and practices for calculating fleet costs and expenses, conducting a survey of DOT fleet managers to identify what problems and concerns related to cost-of-ownership analysis in decision making, developing a standardized activity-based costing methodology, and developing a guide for quantifying the total costs of ownership.

◆ **Project 14-41**

Update Permanent Vegetation Control (Barriers) for Roadsides

Research Field: Maintenance
Source: California
Allocation: \$200,000
NCHRP Staff: Waseem Dekelbab

Permanent vegetation control (barriers) is a group of vegetation control methods that use inert surface materials to prevent or significantly retard the growth of unwanted vegetation. Existing guidelines for this treatment are found in *Guidelines for Vegetation Management, March 2011* by AASHTO. However, the information needs to be updated as new and better technology and methods have become available since 2011. Using permanent vegetation control reduces the need for chemical and manual vegetation control and reduces worker exposure to traffic. Permanent vegetation barriers need to prevent erosion, protect the integrity of highway surfaces, and protect nearby sensitive environmental resources (e.g., endangered species, other sensitive animals and plants, archaeological sites, Native American gathering sites, and environmental mitigation sites). Control of vegetation along roadsides is required for fire prevention, providing adequate sight distance, facility inspection needs, reducing invasive and nuisance weeds, promoting roadside aesthetics, and protecting highway appurtenances such as guardrails, cable barriers, and signs. Locations where permanent vegetation control is particularly important include, but are not limited to, guard rails, cable barriers, signs, road edges, and other roadside assets. Permanent vegetation control is also necessary to sustain the transportation system and promote both worker and traveler safety. Therefore, an approach to permanent vegetation control is desired that effectively suppresses weeds, is simple and economical to use, does not interfere with the performance of the guardrail, cable barrier, and roadside signs, allows for easy repairs, can be applied to new and existing roadside safety appurtenances, and is aesthetically pleasing. Ideally, this permanent vegetation control treatment can also be used for other applications such as road edges, gore areas, maintenance access roads, and maintenance vehicle pullouts.

The objectives of this research are to: (1) update Section 12.0, Permanent Vegetation Control (Barriers), in the AASHTO *Guidelines for Vegetation Management, March 2011*; (2) provide new guidance on permanent vegetation control for cable barriers and roadside signs; and (3) review the entire guide for any other pertinent updates regarding vegetation management that have occurred since its publication.

◆ **Project 15-67**

Improved Methodology to Accurately Determine Wind Drag Coefficients for Highway Signs and Their Support Structures

Research Field: Design
Source: Iowa
Allocation: \$300,000
NCHRP Staff: Waseem Dekelbab

Given that wind is the main load that affects highway signs during their lifetime, accurate estimation of wind loads is essential. Moreover, the cyclic oscillations of the total wind load associated with vortex shedding behind the signs may be a main contributor to premature fatigue failure. This is because these cyclic oscillations, which occur even under steady incoming wind conditions, can create a resonance condition. This resonance causes relatively steady, large-amplitude vibrations of support structure members if the shedding frequency coincides with a natural vibration frequency of the structure supporting the traffic sign. To conduct such structural analyses, one needs data not only on the mean pressure drag force, but also on the dominant frequencies and amplitude/energy of the unsteady pressure force oscillations cause by vortex shedding. Besides the wind loads acting on the signs, the sign support structures are also subject to direct wind loads. Accurate determination of these wind loads requires being able to provide estimates of the drag coefficients for different members of the support structure.

The proposed research will use results from state-of-the-art 3D numerical simulations of airflow around traffic signs and the structures supporting those signs to accurately determine drag coefficients for signs of differing shapes and how these coefficients vary with the main geometrical parameters. It will also develop a new methodology to better estimate wind loads on structures supporting various signs. Finally, it will provide a methodology to estimate the inputs needed to perform structural analyses to investigate if vibrations induced by vortex shedding behind the sign can be a main contributor to fatigue failure. The new design recommendations and methodologies will be written in a form that will be suitable for inclusion in future AASHTO LRFD LTS specifications.

The objectives of this research are to: (1) determine mean (time-averaged) drag coefficients needed to estimate wind pressure loads for typical highway signs placed at a certain distance from the ground; (2) develop new methodology to estimate wind loads on the members of the structures supporting highway signs using data from 3D simulations of flow past signs mounted on support structures; and (3) provide quantitative information needed to perform structural analyses to determine if fatigue induced by vortex shedding may be a concern and, if so, to test mitigation devices for reducing or eliminating wind-induced vibrations of support structures for highway signs.

◆ **Project 15-68**

Effective Low-Noise Rumble Strips

Research Field: Design
Source: AASHTO Noise Work Group
Allocation: \$700,000
NCHRP Staff: Waseem Dekelbab

Preliminary studies by Caltrans and Minnesota DOT indicate significant potential of sinusoidal rumble strips to provide adequate alerting noise while significantly reducing exterior noise. Other designs have been placed extensively by a number of state agencies to address noise, pavement width, or bicycle accommodation issues without documented studies of their comparative safety effects or noise concerns. Other states are interested and have begun exploring the effectiveness and appropriateness of sinusoidal designs. Unfortunately, noise is a very complex issue, and very few state DOTs have appropriate expertise to adequately understand and analyze the complexities of the trade-offs. Likewise, evaluation of safety performance requires a clear understanding of the traffic safety issues and appropriate statistical expertise to understand the complexity of analysis. While there have been a few independent studies of the noise associated with various rumble strip designs, they are difficult to compare because they use different vehicle types, different acoustical equipment and procedures, and have studied different rumble strip designs. Due to the scope of the issue, expertise from both traffic safety and noise professionals is required to answer the outstanding issues. State, local, and federal agencies need definitive answers at a national level on design alternatives to alert drivers that they are drifting from the lane while producing minimal additional road noise from incidental hits. If possible, a model should be developed that could be used for future rumble strip designs and different vehicle types. This would reduce the cost and effort of additional studies by individual agencies.

The objectives of this research are to: (1) conduct field testing of alternative rumble strip designs that can maximize the alerting noise and vibration within vehicles while minimizing external noise increases, accounting for the primary vehicle types within the current fleet and major pavement types, and (2) develop a modeling procedure to allow future rumble strip designs to be analyzed with minimal need for field testing.

Providing state, local, and federal agencies with recommended rumble strip designs that provide adequate alerting stimuli and little to no external noise would greatly expand the opportunities for agencies to reach safety performance goals by continued reductions in roadway departure crashes that account for over half of all traffic fatalities in the United States. Additional benefits may be seen in the future as safety and environmental professionals work hand-in-hand to solve problems together with win-win results.

◆ **Project 17-85**

Applications and Use of Crash Severity Safety Performance Functions

Research Field: Traffic
Source: AASHTO Standing Committee on Highway Traffic Safety
Allocation: \$600,000
NCHRP Staff: Mark S. Bush

As the *Highway Safety Manual* (HSM) continues to evolve, determining the potential severity at a location becomes an increasingly vital component to determining safety performance. For safety performance functions (SPFs) to be reliable they must be consistent. Consistency in how states apply stand-alone severity or severity with frequency based tools and estimates are a fundamental requirement for the adoption and use of the HSM and its associated tools. Consistency is a function of several factors: (a) results that are in general agreement from a multitude of analytical techniques available to practitioner, (b) availability of data sources that allow for broad state and interstate analysis, and (c) interpretability of results for policy application at the national, state and local agency levels. Severity analysis tools as currently available in the HSM do not fully meet this definition of consistency for various reasons, but primarily originating from the fact that the various analytical techniques available in the published literature do not agree in terms of consistency in estimation of crash severity probabilities and crash severity frequencies. Three factors were critical to the adoption of safety analysis techniques used in the HSM: (1) integrity with network screening methods (Part B of the HSM), (2) data availability and requirements, and (3) model predictive performance (Part C of the HSM). The differences in severity estimations can be significant, from the methods currently in use that adopt the observed severity ratios to emerging methods that analyze the severity aspects at multiple scales from the spot, corridor, or network crash levels

The primary objective of this research is to evaluate the various severity estimation methods in terms of the development of reliable safety performance functions. Crash prediction model results are currently being used to make project level and programmatic decisions without complete understanding of their reliability. Specific examples include lack of understanding of compounding errors due to lack of accuracy in severity estimations, use of models at or near their known limits, poor understanding of model limits, and inclusion of crash severity ratios to geographies where severity ratios as well as severity type definitions may not be transferable. Continued use of models in this way may lead to suboptimal design of projects, degradation of model credibility, and open concerns of liability and public trust. The guidelines developed with this research could both address these concerns and promote better-informed engineering judgment in the model application, greater implementation of crash prediction models, and better acceptance of model results, leading to improved decision making.

The guidelines developed with this research will be able to be applied to existing crash prediction models and will serve to improve all future models and model elements throughout the HSM and associated tools.

◆ **Project 17-86**

Estimating Effectiveness of Safety Treatments in the Absence of Crash Data

Research Field: Traffic
Source: AASHTO Standing Committee on Highway Traffic Safety
Allocation: \$600,000
NCHRP Staff: Mark S. Bush

Crash modification factors and functions (CMFs) are developed from historic crash data and help safety professionals estimate the expected safety impacts of specific roadway treatments. There has been a significant amount of research to develop CMFs for common safety strategies and the AASHTO *Highway Safety Manual* (HSM) and FHWA CMF Clearinghouse website contain many CMFs. However, there are many instances in which developing reliable CMFs with conventional crash-based evaluations is less than desirable or simply not possible. For example, using crash data to evaluate innovative intersection designs or new traffic control strategies requires years of waiting to accumulate a sufficient number of installations and crash history. Additionally, countermeasures that improve safety for rare crash types, such as pedestrian crashes, are often lacking in quality CMFs because crash data is limited. Research is needed to develop and apply new methods to developing such CMFs, specifically through the application of surrogate measures of safety such as conflicts, speed changes, and lane deviations. This approach has shown significant promise in recent research.

The objective of this research is to develop procedures for using surrogate measures of safety for estimating CMFs. The procedures will be evaluated by applying them to develop CMFs for specific safety treatments, which will be identified based on a gap analysis conducted as part of this project. To better understand the issue, the research should include an initial review of related research and a gap analysis to identify safety treatments for which needed CMFs may be developed using surrogate measures. Types of surrogate measures that could potentially be used for each treatment should be identified early on, as well. Once candidate procedures have been identified, the procedures will be fully developed and then evaluated by applying them to selected safety treatments to develop CMFs. It is expected that several new CMFs will be developed in the process, spanning a range of site, severity, and crash types and using one or more surrogate measures of safety.

One of the expected products of this project is set of crash modification factors or functions for specific safety treatments that can be incorporated in a future edition of the HSM. Another expected product of this project is a guideline document that describes new procedures for estimation and validation of crash modification factors to support informed decision making during project planning, project development, and other road safety management activities.

◆ **Project 17-87**

Enhancing Pedestrian Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities

Research Field: Traffic
Source: Florida and Virginia
Allocation: \$700,000
NCHRP Staff: William C. Rogers

In 2014, 4,884 pedestrians were killed and an estimated 65,000 were injured in traffic crashes in the United States. The vast majority of the fatalities occurred in urban areas, and most of those were at non-intersection locations. In order to develop pedestrian safety countermeasures, accurate methods for counting pedestrians are needed to quantify exposure, and, in turn, evaluate the benefits of the pedestrian countermeasures. However, pedestrian counts are rare and often only collected on a project basis. The majority of pedestrian counts are conducted manually over a short duration (2 hours are most common), and while automated pedestrian counters are emerging, they lag automated bicycle counters. In addition, pedestrians move in many directions and often do not follow dedicated routes, thus making it difficult for automated counters to count them accurately. Furthermore, pedestrians moving in groups make it difficult for counters to capture accurate data.

In January 2015, Secretary of Transportation Anthony Foxx challenged community leaders to raise the bar for bicyclist and pedestrian safety by joining the Mayors' Challenge for Safer People and Safer Streets effort. More than 230 cities have joined the Mayors' Challenge to improve conditions of walking and biking. Roadway designs and redesigning signal phasing that address the safety of all road users (including pedestrians, bicyclists, and drivers) are being implemented in many cities around the country. These roadway designs often include road diets with corner bulb-outs and/or sidewalk extension, addition of bike lanes, crosswalk widening, and addition of corner or median refuge areas. All these activities highlight the need to develop *Highway Capacity Manual* (HCM) pedestrian methodologies, currently missing in this widely used manual, for safe and sustainable communities.

The objectives of this research are to: (1) develop guidance for jurisdictions on (a) pedestrian counting techniques, technologies, and exposure estimation for safety analyses, including how to select the appropriate time and location for data collection; (b) factors that impact pedestrian travel patterns; and (c) evaluating the latest automated technologies, including social media, for conducting pedestrian counts; (2) determine field-observed factors affecting pedestrian flow at facility levels (sidewalks, corners, and crosswalks) and integrate those factors into the HCM pedestrian analysis methodologies; and (3) determine how safety improvements on the roadway and signal timing designs (e.g., sidewalk extensions, corner bulb-outs, implementing Leading Pedestrian Phase-LPIs) should be correctly reflected in the HCM pedestrian LOS analysis results.

Note: This project statement reflects the AASHTO Standing Committee on Research's direction that problems 2018-C-08 and 2018-G-02 be combined into one project.

◆ Project 17-88

Roadside Encroachment Data for All Vehicle Types Across a Range of Traffic Volumes

Research Field: Traffic
Source: AASHTO Technical Committee on Roadside Safety
Allocation: \$675,000
NCHRP Staff: Edward T. Harrigan

Run-off-road (ROR) traffic crashes account for almost one-third of the deaths and serious injuries each year on US highways. Effective design of roadsides, including the placement of roadside safety devices, can reduce the frequency and/or severity of these crashes but requires an understanding of the nature and frequency of roadside encroachments. Unfortunately, the best quality encroachment data currently available were collected in the 1960s and 1970s and only for passenger vehicles. The age of these data sets suggests that they are no longer representative of the current vehicle fleet or highway conditions. Furthermore, each of these data sets has significant limitations, including specific exclusion of heavy vehicles and motorcycles, and a very limited range of traffic volumes (i.e., less than 20,000 vehicles per day), that have fostered much debate over the present value of the data.

There is a critical need to collect new roadside encroachment data to understand the frequency and nature of encroachments across the entire vehicle fleet. There has been immense progress in both the development of new roadside safety devices and in the improvement of existing devices since the 1960s. Proper development, testing, and placement of these devices along the roadside, however, is required to maximize their effectiveness. The guidelines for development, testing, and placement of these devices rely heavily on provision of reliable roadside encroachment data across a range of traffic volumes and vehicle types.

This research will support the Technical Committee on Roadside Safety's (TCRS) Strategic Plan. The plan's objectives are to lead roadside policy development, support safety innovations, and identify standards that are outdated, lacking, or not supported by recent evidence within the current AASHTO *Manual for Assessing Safety Hardware* (MASH). Collection of new encroachment data will be used to refine current crash testing procedures as well as update the *Roadside Design Guide* (RDG).

The objective of this research is to develop a current understanding of roadside encroachments at a variety of traffic volumes and posted speeds across the entire vehicle fleet. Roadside encroachment data shall be collected for roadways with a range of ADT values and vehicle types. These data shall include the pre-encroachment conditions (e.g., on-road conflict, distracted driving, drowsiness) and highway characteristics, and will be used to study the need for the incorporation of buses and other heavy vehicles into various guidelines within the RDG, as requested by the National Transportation Safety Board (NTSB). The research shall collect both reported and unreported roadside encroachments that result in a crash and concurrently observe intentional and unintentional encroachments within identified sections of roadway.

Accomplishment of this objective shall require the following tasks, at a minimum: (1) conduct a literature review of existing and potential methods for the collection of encroachment data, including modern electronic surveillance techniques; (2) identify agencies willing to participate in this study through sharing their crash databases and road inventory data, and allowing the project team to monitor encroachments; (3) design a data collection procedure/system intended to monitor encroachments on a given roadway segment, including a cost estimate for implementing the procedure/system as well as the size of the expected encroachment database; (4) submit an interim report describing findings from Tasks 1-3 with a work plan for project completion; (5) collect encroachment data using the approved work plan in cooperation with participating agencies; (6) analyze the resulting encroachment database to determine (a) encroachment frequency for a range of traffic volumes, (b) how the encroachment frequency is impacted by the highway characteristics, including, but not limited, to horizontal and vertical alignments, Level-of-Service, number of lanes, lane width, access density, etc., (c) reported and unreported crash thresholds for various roadside hazards and features, and (d) if heavy vehicles, buses, and motorcycles encroach differently than passenger vehicles and should therefore be specifically addressed within the RDG and MASH crash testing procedures; and (7) prepare a final report that documents the entire research

effort with recommendations for the refinement of the RDG and MASH.

◆ Project 17-89

Safety of Part-Time Shoulder Use and HOV/HOT Lanes

Research Field: Traffic
Source: AASHTO Standing Committee on Highway Traffic Safety
Allocation: \$700,000
NCHRP Staff: Edward T. Harrigan

This research addresses the safety of two distinct but related designs for increasing freeway operational performance: part-time shoulder use and High Occupancy Vehicle/High Occupancy Toll (HOV/HOT) lanes.

Part-time shoulder use is an increasingly popular and practical performance-based design strategy for both reducing freeway congestion and improving bus travel time and reliability. In general, there are three types of part-time shoulder use: bus-on-shoulder (BOS), static shoulder use, and dynamic shoulder use. BOS is limited to authorized buses driven by trained drivers. Static shoulder use and dynamic shoulder use allow all or most vehicles to use the shoulder when it is open; some facilities prohibit trucks from using the shoulder. Static shoulder use opens the shoulder to traffic on a fixed schedule, and dynamic shoulder use opens the shoulder to traffic in response to traffic conditions. Sixteen states have one or more part-time shoulder facilities in operation, and many of these have opened within the past five to ten years. FHWA published a guide on part-time shoulder use in February 2016, and the lack of tools for quantifying the safety impact of part-time shoulder use was identified as a major research gap by the guide's authors.

The current Highway Safety Manual (HSM) freeway models cannot be used to evaluate the potential safety performance of part-time shoulder use. Observed crash data along with other operations aspects of part-time shoulder use cannot be modeled using HSM freeway chapters because these predictive models do not address shoulder use in particular.

While it may not be possible to develop crash prediction models for part-time shoulder use at this time, research is needed to develop a quantitative safety analysis of the part-time shoulder use operations as well as documentation and guidance that provide the profession a better understanding of the potential tradeoffs as well as the elements that create successful (limited collisions) operations. A quantitative safety assessment will highlight the critical data elements needed for a safety analysis—crash types, start and end time of part-time shoulder operation, temporal and spatial characteristics of crashes, distance from the entrance ramp and exit ramp, AADT on the general purpose travel lane, etc.—obtained from existing observed crash data of at least three to five years from different facilities across the country. The analysis will further consider volume and basic geometric information (such as the number of lanes) as crash predictors as well as temporal factors such as density, speed, and lane-by-lane variations of the two. There is evidence these factors impact freeway crash frequency, and facilities with changing lane configuration may be more impacted. This aspect of the research will address Themes 3.3 and 4.4 of the action plan in the current AASHTO SCOHTS strategic safety plan.

HOV/HOT lanes are involved in many recent traffic operational improvements for urban and suburban freeways in the U.S. The term 'managed lanes' has been applied to the overall practice and both HOV and HOT lanes are examples of managed lanes. According to the TRB Committee on Managed Lanes database of facilities, the total centerline mileage of electronically tolled HOT facilities in the country is around 1145 lane-miles. The physical separation of the general-purpose and HOV/HOT lanes usually varies from 2 to 22 feet and may make use of a buffer zone or barriers like channelizers and bollards. As more agencies retrofit existing HOV lanes to HOT or introduce a managed lane into an existing corridor, fewer separation barriers are being built. These geometric and operational aspects of HOV/HOT facilities impact safety on the entire facility in urban and suburban freeway sections.

Design elements of freeways with HOV/HOT lanes that influence safety include lane orientation (i.e., contra-flow or concurrent flow), lane access type (i.e., continuous or limited), and lateral separation from general purpose lanes (i.e., buffer or barrier). Research indicates that the addition of HOV lanes can increase crashes, depending on the tradeoffs made between components of the full freeway cross section. Increasing the buffer width can reduce crashes, provided that this additional buffer width does not lead to compromises in the width

of the traffic lanes or shoulders. A few states have added flexible tubular delineators to the buffer; however, anecdotal evidence is that safety is degraded by these supplemental devices. The toll facilities associated with HOT lanes represent an area of increased lane changing and queuing. These characteristics are likely to increase crash risk, especially if the area provided for lane changing and queuing is constrained. The safety effect of toll facilities is also likely to be influenced by the percentage of vehicles that use electronic toll tags.

Research is needed to develop a safety prediction method that can be used to estimate the expected crash frequency of a range of freeway facilities with HOV or HOT with various geometric and traffic volume characteristics. The method will provide information useful to the planning and design of these facilities, and, thus, it must be sensitive to a wide range of HOV and HOT lane design elements. This aspect of the research will address Themes 4.4 and 6.6 of the action plan in the current AASHTO SCOHTS strategic safety plan.

The objectives of this research are to quantify and expand the knowledge base of safety performance of part-time shoulder use (Part A) and to develop a predictive methodology to estimate crash frequency and severity for freeway facilities, and associated ramps, with HOV or HOT lanes (Part B).

In Part A, the research shall determine how the safety performance of freeways with part-time shoulder use differs from the safety performance of freeways without shoulder use and how the safety performance of freeways with part-time shoulder use varies based upon traffic volumes and the design and operating features of the shoulder. Further, the research shall distinguish between bus-on-shoulder (BOS) operation and shoulder use open to general purpose traffic (static or dynamic shoulder use). Static and dynamic shoulder use shall be grouped together due to the similar operating characteristics, the existence of static facilities that incorporate some elements of dynamic facilities, and the small number of existing dynamic shoulder use facilities.

This research shall specifically exclude shoulder use in work zones, conversion of a shoulder into a full-time (24 hour a day) lane, and shoulder use on arterials.

In Part B, the research shall address the development of predictive methodology to help highway agencies consider safety in decisions about planning and designing freeways with HOV or HOT lanes on urban freeways. The predictive methods shall include safety performance functions, crash modification factors (CMFs), and calibration factors in a format that is consistent with the predictive methods in the existing HSM Part C. Separate predictive methods shall be developed for freeways and interchange ramps with HOV or HOT components. The methods shall be sensitive to the traffic volumes on the freeways and ramps and to the geometric design elements and traffic control features considered by engineers and planners during the project development process. Coordination of the research is required with the joint AASHTO/TRB activities related to the HSM, FHWA's Interactive Highway Safety Design Model (IHSDM), AASHTO's *SafetyAnalyst* software tools, the 3rd Edition of the Human Factors Guide, and the Towards Zero Deaths strategic highway safety planning initiative.

Note: At the direction of the AASHTO Standing Committee on Research, NCHRP Project 17-89 combines the objectives of problem statements 2018-B-12, "HOV/HOT Crash Prediction Method for the Highway Safety Manual," and 2018-G-03, "Safety Performance of Part-Time Shoulder Use." The NCHRP project panel will decide whether to conduct research to accomplish the two objectives as one project or two.

◆ **Project 19-15**

Guidebook for Effective Debt Management Policies and Practices for Surface Transportation

Research Field: Administration
Source: Arizona
Allocation: \$300,000
NCHRP Staff: Lawrence D. Goldstein

Given an increase in the amount and types of financings being used to pay for transportation investments coupled with an increasingly complex regulatory environment for municipal debt, state DOTs are facing a number of challenges in administering and managing their debt programs. These challenges include: (1) maintaining an affordable level of debt; (2) complying with post issuance compliance requirements; (3) determining the appropriate debt tool to use to meet financing needs; (4) determining when it is appropriate to refund existing debt; (5) selecting qualified advisors including bond counsel, financial advisors, investment bankers, and trustees among others; (6) selecting the appropriate issuance method; and (7) communicating to stakeholders parameters affecting debt affordability. To overcome such challenges, state DOTs regularly seek to improve debt management policies and procedures.

State DOTs have a wide range of policies in place to guide the management of their debt programs. Such policies cover types of debt and related security, debt affordability beyond bond covenant and statutory limitations, method of sale, refunding savings guidelines, use of variable rate debt guidelines, selection of advisors, use of derivatives, debt structuring practices, debt issuance practices, use of credit ratings and selection of ratings services, practices related to investment of proceeds, disclosure practices, post issuance compliance practices, and market and investor relations efforts, among others. Developing and adhering to effective debt management policies that provide guidelines and restrictions regarding the amount and type of debt issued, the issuance process, and the management of the debt portfolio will improve the quality of decisions and provide justification for the use and structure of debt while identifying and monitoring adherence to stated policy goals.

NCHRP Synthesis Topic 47-07, “Evolving Debt Finance Practices for Surface Transportation,” highlighted that state DOTs are issuing an increasing amount of debt and using an increasing variety of financing mechanisms. This increase is occurring while state DOTs find that they are facing greater regulatory scrutiny.

The primary objective of the proposed research is to develop a deeper understanding of the debt issuance and management policies that states follow related to transportation debt. The final deliverable will be a guidebook to help state DOTs develop and implement effective debt management policies. The primary audience for the guidebook will be state DOT financial managers but will also include elected officials, state DOT chief executive officers, and other agencies with a role in providing technical assistance and oversight affecting state DOT financial management.

Based on findings from the earlier NCHRP Synthesis Topic 47-07, and the increasing complexity of debt mechanisms in the broader context of a changing regulatory environment, it is apparent that most DOTs would benefit from access to detailed guidance on debt issuance and potential management policies.

◆ **Project 20-59(56)**

Support for State DOT Transportation Systems Resilience and All-Hazards Programs

Research Field: Special Projects
Source: AASHTO Special Committee on Transportation Security and Emergency Management
Allocation: \$250,000
NCHRP Staff: Stephan A. Parker

Over the past sixteen years, and in partnership with TRB and FHWA, AASHTO and its member organizations have dedicated energy, time and funding resources to deliver many accomplishments in the transportation security, emergency management, and infrastructure protection areas of transportation operations. During this period AASHTO member organizations and others have funded more than 80 NCHRP research projects investigating how best to prepare for, prevent, mitigate, respond to, or recover from weather-related and human-caused disasters, emergencies, and security incidents. Significant institutional, organizational and technical issues are emerging as the transportation community enters the evolving fields of resilience and security. This emerging landscape warrants the strategic focus of AASHTO and its member DOTs as reflected in the AASHTO current and emerging committee and program structures.

Three significant drivers are providing impetus to this initiative:

1. The sunset of SCOTSEM's *4th Generation Strategic Directions (2014-2018)* in 2018. This plan established a foundation in resilience by:

- Placing a renewed emphasis on system users' safety and on protecting transportation investments in an all-hazards context;
- Revising its mission focus on getting "research on the ground," education and outreach;
- Partnering with other AASHTO groups that form the nucleus of the transportation system maintenance and operations community.

NCHRP Projects 20-59(14)C and 20-59(51)C provided implementation support for this Plan and its six goals. An update of the Plan will be necessary and critical in 2018.

2. The AASHTO Committees restructuring initiative is likely to expand the mission and scope of security and resilience activities. Indications are that the new committee structure will consolidate the Association's current committee structure and mission, expand the membership focused on security and resilience and also trigger the need for a new strategic direction.

3. NCHRP Projects 20-59(54), 20-59(55), and 20-59(117) are focused on preparing for and conducting a National Summit and Peer Exchange on Transportation Resilience, scheduled for late 2018. While specific recommendations from this activity are not known yet, many of them will likely affect various committee activities. These impacts will create the need to adjust work plan initiatives, research agendas, training opportunities and other activities, requiring implementation support to rapidly respond to these new opportunities and imperatives.

Both AASHTO and the larger DOT community are entering another period of transition and must continue to sponsor new knowledge transfer, research, and outreach initiatives to advance the state-of-the-practice used by the professional community to deliver timely resilience, security, emergency management and all-hazards protection awareness, information, training, and "on-the-ground" experience to their peers and their customers.

This project has three objectives: 1) assist SCOTSEM (or its successor Committee) in developing a new Strategic Plan covering the period 2019-2023; 2) continue providing support services to assist in accomplishing strategic goals as articulated in a new Strategic Directions Plan; and 3) provide support for post-Summit initiatives. The scope of these services encompasses the following three tasks, plus project management activities.

TASK 1: 2019-2023 Security and Resilience Strategic Plan Development

The research team will facilitate the development of a Strategic Plan for the assigned AASHTO Committee(s). The Plan will include updated Values, Vision, and Mission Statements reflecting the new challenges facing the Committee; and new goals with outcome-oriented performance measures and new initiatives encompassing awareness, knowledge and skill-building, stakeholder outreach, and other activities intended to achieve its goals.

TASK 2: Strategic Directions Implementation

The research team will work with and provide technical and strategic support to AASHTO as it pertains to the Committee's mission and 2018 work program. The research team will provide advice and support to the Committee's Leadership Team and will coordinate with the other AASHTO and TRB initiatives that may influence or be influenced by the Committee. The research team will assist AASHTO staff to:

- Facilitate Research Deployment/Dissemination - The research team will assist with the development of documents outlining activities for dissemination of research results into practice and AASHTO policy.
- Coordinate/Integrate Outreach and Stakeholder Engagement - The research team will assist with stakeholder outreach activities in order to raise the visibility of resilience and security topics within AASHTO, TRB and the DOT community.

TASK 3: Transportation Resilience Post-Summit Support

The research team will synthesize the outcomes of the National Summit on Transportation Resilience and assess the impact and opportunities for SCOTSEM (or its successor). Additional support activities may include but are not limited to:

- Preparing informational products (e.g., infographics, brochures, fact sheets) on significant topics raised during the Summit
- Recommending changes to the Strategic Plan, Work Plan, or Research Plan reflecting post-Summit impacts

◆ **Project 20-102(11)**

Impact of Mobility-on-Demand Services and Highly Automated Vehicles on the Transportation System

Research Field: Special Projects
Source: NCHRP Project 20-113
Allocation: \$200,000 (to be added to \$100,000 already authorized from NCHRP Project 20-102)
NCHRP Staff: Stephan A. Parker

A wide variety of mobility-on-demand (MOD) services have developed and proliferated in recent years. They include carsharing, bikesharing, microtransit, transportation network companies (TNCs) like Uber and Lyft, and many others; while MOD is mainly impacting personal transportation, innovation in freight mobility also needs to be considered. Some of these services have become mainstream means of transportation in certain cities and have been supported on the basis of sustainability. In recent months, key auto manufacturers have partnered with TNCs, profoundly impacting the MOD business model(s) and accelerating its relevance and position in the market place. At the same time, relatively little data, analysis and information are available concerning the impacts of MOD services on existing transportation systems, both private and public. Such information is needed to help close the gap between technological development and needed policy decisions.

This information gap is all the more acute because MOD services affect not only traditional modes of transportation (such as personal vehicles and transit) but also interact with other transformational technologies including highly automated vehicles (HAV), smart cities and communities, and big data analytics. In this context, MOD is a key enabler of disruptive changes in transportation; yet public policy makers risk such disruption occurring in an information vacuum. What is the necessary set of considerations, articulated within a policy framework, for assessing the impact of MOD on transportation systems and their economic and societal ramifications?

A framework for assessing MOD services and the emergence of HAVs must be crosscutting to encompass value for money, affordability, livability, mobility, access to jobs, infrastructure construction, maintenance and operation, economic development, safety, environment and energy. The framework must provide a platform for a wide variety of research questions including:

- How should the impacts of MOD and HAVs on the transportation system be measured?
- How should social inclusion and the “digital and income divide” be addressed?
- What are the safety impacts of these technologies?
- How should the impact on public transit and the economy be assessed?
- How could the wide spectrum of shared mobility services and HAVs be incorporated into regional planning tools?
- What are the effects of MOD services on vehicle ownership and use?
- How do MOD services and HAVs impact parking, urban form, land use and city revenue sources?
- How may cities encourage the sharing of MOD data and the formation of partnerships for analytics and research?

The MOD services and HAV policy framework should focus on the needs of transportation agencies at the state, regional, and local levels; it should also have relevance for jurisdictions beyond transportation, including IT, urban planning and development, housing and real estate, and social welfare. Many agencies lack the expertise to perform evaluations of MOD services or to thoroughly assess proposals provided by vendors. A consistent framework is needed so that all of the potential impacts on transportation policy are considered and alternative approaches can be compared.

Finally, the needed policy framework should provide common ground for public-private collaboration in the deployment of beneficial technologies in transportation. It should facilitate the development of model principles and methods for the planning, deployment, and evaluation of MOD services and HAVs. In particular, it should accelerate the mutual benefits of HAVs, MOD services and smart cities and communities.

The objective of this research is to establish a framework to assess the effects of MOD services and HAVs on transportation demand and supply and the broader ecosystem of economic and societal impacts. A critical part of this framework will be common metrics in areas such as:

- Changes in travel demand;
- Modal split (MOD service, private vehicle, transit, bicycle, walking);
- Safety and congestion;
- Environmental and energy impacts;
- Auto ownership; and
- Effects on parking and land use.

Metrics should be capable of incorporating a broader set of changes, including smart cities and communities, smart infrastructure and supply chains, alternative energy vehicles, and big data analytics. The framework should consider the built environment, existing transportation infrastructure, regulatory considerations, and determination of appropriate spatial and temporal boundaries for analysis.

Cities and states are being approached by private and semi-private sector vendors of MOD services and must determine whether and under what circumstances these services should be allowed in their jurisdiction. Many of these services operate nationally or internationally and can bring significant pressure on the public sector for quick and comprehensive approval. Clear guidance will be very useful in these reviews.

The clear safety and traffic efficiency benefits of HAVs are currently impeded by a range of uncertainties. The integration of HAVs into MOD services represents an important means of HAV deployment, bringing forward and mainstreaming the unprecedented safety benefits of HAV technology. Such deployment requires public-private collaboration based on a clearer mutual understanding of opportunities and barriers. The MOD/HAV framework is an important element in engendering greater trust between the parties.

MOD services are continually evolving and market penetration rates will be inconsistent among regions. Setting common metrics as soon as possible will allow the effects during the initial period to be tracked and remediation actions taken as needed.

Researchers are also evaluating these services using a variety of methods and at a variety of levels, and a consistent approach would streamline the design of these studies and the compilation of meta-studies. The proposed MOD evaluation framework will also assist in revamping the role and effectiveness of transportation research programs. Accelerated and dynamic research approaches are needed to help close the gap between technological development and policy-making activity.

Note: This project is to be combined with NCHRP TT1, “Summary of Existing Studies on the Effects of Connected Vehicles/Automated Vehicles (CV/AV) on Travel Demand.” The combined project is budgeted at \$300,000.

◆ **Project 20-102(15)**

Understanding the Impacts of the Physical Highway Infrastructure Caused By the Increased Prevalence of Advanced Vehicle Technologies

Research Field: Special Projects
Source: AASHTO Highway Subcommittee on Traffic Engineering
Allocation: \$650,000
NCHRP Staff: B. Ray Derr

Vehicle technologies are advancing faster than ever and there is a growing need to better understand how and when the traditional infrastructure will be impacted. Some agencies are starting to question the value of maintaining signs, roadside hardware, and other key physical highway infrastructure (because they might not be needed in the future). While there may be a day in the distant future when vehicles can navigate without any physical guidance, until then, physical guidance has to serve both the human driver and the machine driver. This physical guidance is mostly provided by traffic control devices. Traffic control devices have a long history of research, development, and testing to ensure that human road users can navigate anywhere within the US without having to relearn traffic codes. The MUTCD has evolved over the last 80 years to define a system in which agencies uniformly apply traffic control devices. All of the research, testing, and application guidance provided through the MUTCD has focused exclusively on the human driver. There is a growing and urgent need to assess how traffic control device designs and applications can be modified to accommodate both the human driver and the machine driver.

For the past three years, the TRB Automated Vehicle Symposium has hosted breakout sessions focused on the highway infrastructure. These breakout sessions have been attended by a mix of representation from transportation agencies and the automotive industries. A recurring discussion at these meetings has been related to the need to reassess traffic control device design and application with machine driver concepts in mind. For the past two years, vehicle industry experts have reported examples from their real-world demonstrations of how the existing traffic control device designs and applications appear non-uniform from their perspective and could be improved. According to the available research, there are significant safety and mobility benefits to be gained from advanced vehicle technologies that are not likely to be achieved from other sources.

The overall objective of this research is to assess how elements of the physical highway infrastructure (with an emphasis on traffic control devices) can be designed, enhanced, and/or applied to meet the needs of both the human driver and the machine driver. The research team should work with AV system developers to understand their technologies and processes for handling traffic control devices, including traffic control devices within work zones. The research team should also engage vendors of traffic control device materials regarding potential enhancements and feasibility of new product development. Existing research and innovations in retroreflectivity and other characteristics in traffic control devices should be included. The deliverables should include a detailed assessment of the current challenges as seen from the AV system developers as well as the highway owners and operators, suggestions to overcome those challenges with specific examples, implementation suggestions, and a roadmap outlining additional research, analysis, and milestones.

◆ **Project 20-121**

State DOT Contributions to the Study, Investigation, and Interdiction of Human Trafficking

Research Field: Special Projects
Source: Delaware
Allocation: \$300,000
NCHRP Staff: Stephan A. Parker

Human trafficking is defined as the recruitment, harboring, transportation, provision, or obtaining of a person for labor or services through force, fraud, or coercion for the purpose of involuntary servitude, peonage, debt bondage, or slavery. Human traffickers in the United States utilize national, state, and local transportation infrastructure and systems to transport men, women, and children for forced labor and/or sex commerce. Research shows that there is limited insight and understanding of human trafficking networks, and this lack of information impedes investigation, interdiction, and decision support related to human trafficking by law enforcement agencies. In particular, traffickers operate clandestine networks and victims of trafficking do not self-identify. These characteristics of human trafficking confound the efforts of law enforcement and the partner agencies they may rely on, such as state DOTs and their employees.

A sporadic, piecemeal approach to prosecution impedes deterrence nationally, since different states use different statutes to approach these crimes. With respect to the sexual exploitation of minors, for example, some prosecutors use solicitation statutes, while others charge under human trafficking statutes. Additionally, most law enforcement entities have not directed staff to collect human-trafficking-related data. Where relevant information is collected, it is rarely coded properly for easy access and sharing; and with respect to data sharing, interoperability issues impede partnering. The producers and “stewards” of the types of data potentially useful to understanding human trafficking often do not have incentives (nor even the awareness) to actively share the data. For example, technologies and data collection supporting the transportation system may produce information useful to the investigation and interdiction of human traffickers, as well as the identification of victims, but data needs to get into the right hands.

Contributions from state DOTs are needed to support the enforcement of human trafficking laws; help victims (e.g., rescuing them and connecting them to services); and provide improved decision support for policy, operations, etc. There are several actions that state DOT personnel can take to gain awareness and justify the use of resources to supply valuable information that supports anti-human trafficking efforts. These actions include the following: knowing the signs of human trafficking; collecting actionable information; utilizing the national human trafficking help line; cooperating with requests from internal and external law enforcement for information that can be derived from transportation agency assets or personnel; and investment in, and use of, helpful technologies. Also, through more strategic efforts to support anti-human trafficking efforts, state DOTs can support data availability, quality, and usability (to ensure legal sufficiency) and thereby support successful investigations, interdiction, and decision-making.

Many transportation professionals are not familiar with the problem of human trafficking; and while some have awareness, their knowledge may be limited to ad hoc experiences. It can be challenging to rally the resources needed to educate employees on the scope of the problem and on the specific steps they can take—through planning, programming, and daily operations—to mitigate it. This project will inform state DOTs interested in developing structured responses to human trafficking appropriate to their states, and in supporting their employees who may be on the front lines against criminal activity.

The objective is to identify the mechanisms that state DOTs are using to assist law enforcement in combatting human trafficking, assess their effectiveness, and develop high-level guidance for state DOTs supporting law enforcement and other authorities in the study, investigation, and interdiction of human trafficking. The research product would be a Handbook and model presentations for senior managers and field staff.

Human trafficking is modern-day slavery, with victims suffering physical, economic, and social harms. Its victims often appear complicit, by refusing to identify themselves or to otherwise assist law enforcement. To society, the negative aspects of human trafficking include public health threats, e.g., epidemics, and the illegal

activities funded by human trafficking, such as terrorism and racketeering. Unlike illicit drug trafficking, the “commodity” involved in human trafficking can be used again and again, making for a lucrative trade.

State DOTs have several potential roles. A state DOT’s driver identification programs and other documentation services can generate leads; and oversight of license plates, vehicle registration, routing, and permitting provides a view into trends in commercial and individual driver behavior. The regulatory relationship with the transportation sector creates ties that can be leveraged for non-regulatory interaction. In some state DOTs, staff have become “ambassadors” to motor carriers on the human trafficking issue. They supply group training, for example, with significant results. A few years ago, state DOT staff engaged a Missouri carrier in outreach, and that carrier provided training to its employees. A Florida-based employee of the carrier received the training, and, while in transit sometime later, spotted strange behavior at a Virginia truck stop. He reported the fleeing incident, and, as a result, authorities freed an Iowa woman from sexual slavery.

Close coordination with law enforcement is extremely important in addressing security in the transportation system. Sample successes in routine collaboration include ITS technologies used to issue “amber alerts” for missing children and the “silver” alert for missing elderly people. Technologies, such as video surveillance systems, thermal cameras, and remote sensing, may be used to support activities to combating human trafficking.

In recent years, human trafficking investigation and interdiction by the Department of Justice and others has increased, in response to directives from the highest level of the US government. The USDOT and the US Department of Homeland Security (DHS) have collaborated on outreach and engagement with transportation industry leaders, unions, and workers. For example, the DHS Blue Campaign against human trafficking trained 55,000 DOT employees and 20,000 contractors. Through USDOT, there is an interactive, web-based “workplace” available anywhere with anti-human trafficking training materials and response protocols. USDOT also has coordinated with the private sector. As a result, Amtrak committed to training 20,000 employees; and commercial airlines, through the “Blue Lightening” initiative, are utilizing training, materials, and safe reporting methods for personnel.

In 2014, TRB held a session on human trafficking at its annual meeting. Federal and state organizations discussed critical issues and initiatives, including the State of Iowa DOT’s collaboration with Truckers Against Trafficking, which has been a model for many states.

In 2016, TRB conducted “Workshop 836: Expanding the Scope of Resiliency: Human Trafficking and Hazardous Materials Concerns” at its 95th Annual Meeting. This workshop built on the 2014 session and included audience interactions that brought forward new information, such as a recent app enabling real-time tips by truckers and others. Also at the 2016 session, Human Trafficking expert Dr. Louise Shelly discussed the reach of trafficking networks across multiple sectors. A presenter from the USDOT examined linkages to freight management. Data strategies for State DOTs were discussed also, as a mechanism for supporting the investigation and interdiction of human trafficking.

The latter session topic, data strategies, can be one focus for this project. An important area of transportation sector assistance in human trafficking interdiction is the identification, collection, preservation, and sharing of actionable information for law enforcement investigations, interdiction, and decision support. The Truckers Against Trafficking model, as adopted by the Iowa DOT, includes activities such as collecting data on the interdiction stops that lead to human trafficking investigations. Good data supports law enforcement success, both in investigations and interdiction. A relevant and well-understood data strategy can sharpen analysis of key issues—numbers of arrests, prosecutions, successful convictions, number of victims (including method of recruitment), routes and patterns of trafficking (states and countries of origin and destination) etc.—for the purposes of policy making, decision support, and coordination with other transportation agencies.

A key task in this project could be to examine current practices at state DOTs and in other transportation modes, resulting in

- Identification of the role(s) of state DOTs in supporting FBI and other law enforcement activities on combatting human trafficking and
- Understanding of policies and practices that state DOTs have implemented and can implement on this topic, including a gap analysis.

The value of the research results would be (1) to raise awareness and (2) to allow states to capitalize on the experience of early adopter states. There is a strong likelihood of implementation-ready products because there is a ready foundation for a handbook, with field-tested tool kits and other efforts in place. This research can pull together existing information, assess it, and develop more detailed guidance on approaches to, e.g., DOT-supported prosecutions, diverse modes (rural interstate v. urban transit center), or other interdiction entry points (e.g., state DOT documentation services). The negative impact of not funding this research is continuation of a “piece-meal” approach that sees DOTs discovering, on their own, the operational practices needed to support law enforcement and fully implement guidance from key partners, such as Truckers Against Trafficking.

Note: The AASHTO Standing Committee on Research discussed several aspects of the topic and how DOT interests intersect with the broad issues the research could entail. NASEM’s Health and Medicine Division should be engaged.

◆ **Project 22-34**

Determination of Zone of Intrusion Envelopes under MASH Impact Conditions for Barrier Attachments

Research Field: Design
Source: AASHTO Technical Committee on Roadside Safety
Allocation: \$400,000
NCHRP Staff: Waseem Dekelbab

Highway agencies are often presented with a need to add attachments, such as pedestrian and bicycle railings, highway signage, high-protective screening fences, luminaire poles, etc., to the top or backside faces of crash-tested traffic barriers. However, attachments such as these have been shown to act as vehicle snagging hazards and ultimately degrade the safety performance of the barrier system. Thus, the Zone-of-Intrusion (ZOI) concept was developed to address this issue. ZOI represents the locations above and behind a barrier system that various vehicle components may occupy during an impact event. ZOI envelopes provide guidance for safe placement of barrier attachments to reduce the risk of vehicle snag on the attachments.

Current ZOI guidance was developed based on existing *NCHRP Report 350* TL-2, TL-3, and TL-4 testing. However, AASHTO and FHWA recently agreed to the implementation of the new MASH crash testing standard, and MASH utilizes different standardized vehicles, which may significantly change barrier ZOI. Specifically, the MASH pickup truck, utilized in TL-2 and TL-3 evaluations, has an increased weight and a higher center-of-gravity than the previous *NCHRP Report 350* pickup truck. Additionally, MASH increased the weight of the single unit truck by 25 percent and increased the impact speed for TL-4 impacts. Thus, it is expected that the ZOI envelopes for these vehicles will increase in size under the MASH criteria. The increases in weight and impact angle for MASH test 4-12 has also led to an increase in the minimum height from 32 in. to about 36 in. for TL-4 barriers. Changes to the barrier shape, especially height, will likely have significant effects on the shape of ZOI envelopes for TL-4 barriers. Therefore, a need exists to revisit the ZOI guidance for MASH impact conditions and barriers.

The objective of this research project is to develop ZOI for a variety of rigid barriers under MASH impact conditions. The heights of the barriers will range from 20 in. to 42 in., while the barrier shapes to be evaluated include New Jersey Shape, F-Shape, Single Slope, and Vertical shaped barriers. The ZOI for each barrier geometry will need to be determined for different impact conditions as well, including MASH TL-2, TL-3, and TL-4. ZOI will be developed independently for each combination of barrier shape, barrier height, and MASH test level (impact condition). Thus, guidance shall be provided for specific roadway and barrier conditions, not just a uniform blanket ZOI encompassing a variety of installations.

◆ **Project 22-35**

Bridge Rail Testing Program to Confirm MASH Compliance

Research Field: Design
Source: AASHTO Technical Committee on Roadside Safety
Allocation: \$500,000
NCHRP Staff: Waseem Dekelbab

The AASHTO Technical Committee on Roadside Safety (TCRS) and FHWA have adopted a new MASH implementation plan that has compliance dates for installing MASH hardware that differ by hardware category. After December 31, 2019, all new installations of bridge rails on the NHS must have been successfully evaluated according to the 2016 edition of MASH. The FHWA will no longer issue eligibility letters for bridge rails that have not been successfully evaluated relative to MASH performance criteria.

There are many types of non-proprietary (generic) NCHRP 350 bridge rails in use throughout the states. With the recent adoption of a new joint AASHTO/FHWA implementation agreement, there is a need to review these current NCHRP 350 bridge rail systems and determine the level of evaluation required to demonstrate MASH compliance. NCHRP Project 20-07, Task 395, “MASH Equivalency of NCHRP 350-Approved Bridge Railings” is currently underway to evaluate the most common, highest priority railing systems such as concrete bridge rail systems (F-shape, single slope, vertical wall, etc.) with consideration given to different rail categories and features. It is fully anticipated that additional full-scale testing will be required for state DOT rail systems whose performance is uncertain and for which this proposed NCHRP project is dedicated to. The additional research is needed since it is anticipated that NCHRP Project 20-07, Task 395, will leave out many systems that will not be ruled eligible by FHWA and additional analysis and crash testing efforts will be needed to cover the common state DOT bridge railing systems. The results of each task become recommendations to AASHTO to serve as interims to all existing AASHTO Design Manuals (i.e., Geometric Design of Highways and Streets and LRFD Bridge Design Specifications).

The objectives of this research are to: (1) determine the remaining bridge railing systems to be reviewed and crash tested based on outcome of current NCHRP Project 20-07, Task 395, and literature search of any other state systems; (2) conduct LSDYNA Finite Element Analysis computer simulation as per *NCHRP Web-Only Document 179*, and crash testing of remaining state systems; (3) provide recommendations on these systems and request FHWA eligibility letters for MASH conformance as needed; (4) provide information to AASHTO TCRS, AASHTO SCOBS T-7, and state DOTs for their use; and (5) review/update existing FHWA Memorandum “Information - Bridge Rail Analysis” (dated May 16, 2000).

◆ **Project 22-36**

Development of the Next Generation, MASH, Portable Concrete Barrier

Research Field: Design
Source: AASHTO Technical Committee on Roadside Safety
Allocation: \$400,000
NCHRP Staff: Waseem Dekelbab

Currently, most non-proprietary portable concrete barrier (PCB) systems in use on the nation's highways are New Jersey safety shape or F-shaped barrier segments, composed of reinforced concrete and simple pinned connections that allow rotations between segments. Three problems exist with this basic design: (1) the stepped, sloped face of the barrier often allows impacting vehicles to climb and roll as they impact the barrier, causing vehicle instabilities that can result in rollover; (2) the segment connections allow significant rotations prior to loading the adjacent segment, resulting in high lateral deflections upon vehicle impact, up to 80 in. for impacts with pickup trucks. Where deflections must be limited, anchoring or pinning of the segments into the pavement is required, which impedes installation and removal, exposes workers to traffic hazards, and causes pavement damage and (3) the bottom toes of the barrier segments are often under-reinforced, which often results in the toes fracturing off the segments when loaded during impacts or even during transportation and placement of the segments. Significant damage to the toe of a segment impairs barrier performance, thus requiring segments to be replaced often.

In an effort to encourage state DOTs and hardware developers to advance their hardware designs, the Federal Highway Administration (FHWA) and AASHTO have collaborated to develop a MASH implementation policy that includes sunset dates for various categories of roadside hardware. The new policy will require that devices installed on federal-aid roadways after the sunset dates must satisfy MASH. Temporary work-zone devices, including portable barriers, let on projects after December 31, 2019, must have been successfully tested to MASH 2016. Devices used on projects let before this date may continue to be used throughout their normal service lives. Thus, an opportunity exists to develop a high-performance PCB system that meets the MASH safety criteria as well as address the deflection, stability, and durability concerns of most current PCB designs.

The objective of this research project is to develop a new, high-performing PCB design that is as economical as widely used PCB existing systems and meets the following criteria: (1) satisfy MASH Test Level 3 crash testing requirements; (2) reduce the potential for post-impact vehicle instability, specifically reduced roll and vehicle climb as compared to existing PCB systems; (3) minimize system deflections (less than current NCHRP 350 deflections and to the greatest extent practical); (4) are free-standing with no anchoring or connections to the ground required, but anchoring available; (5) ensure installation and removal times comparable to existing PCB systems; (6) transport and delivery comparable to existing PCB systems; (7) increase durability over existing PCB systems; and (8) are non-proprietary.

◆ **Project 24-48**

Develop a Formula for Determining Scour Depth around Structures in Gravel-bed Rivers

Research Field: Soils and Geology
Source: Washington
Allocation: \$600,000
NCHRP Staff: Waseem Dekelbab

In the current state of engineering practice, there is a recognized lack of formulas for predicting the scour depth around hydraulic structures, such as bridge piers, abutments and barbs, in gravel-bed rivers. The majority of scour depth prediction formulas presently in use have been developed for sand-bed rivers and, as such, do not account for fundamental processes and characteristics that are unique in gravel-bed rivers. For instance, the inhomogeneity of gravel particles promotes particle interlocking armor development. At the same time, unique turbulent structures result from the interaction of the non-homogeneous material with the approach flow. Even after correcting their scour depth predictions using empirically derived coefficients to account for these processes, the traditional scour prediction formulas originating from sand-bed rivers still overpredict scour depths in gravel-bed rivers. Recent insights into gravel-bed river dynamics along with advances in sensing technologies, such as RFIDs and Ultrasonic Transducer Arrays, have improved understanding of these gravel-bed river processes and for the first time allow the development of a scour prediction formula that directly accounts for their effects.

The objectives of this research project are to: (1) investigate the effects of gravel interlocking and of turbulent structures, such as the horseshoe and wake vortices, generated in gravel-bed rivers on scour around hydraulic structures; and (2) develop a physically based formula for predicting scour depth around hydraulic structures in gravel-bed rivers that accounts for the sediment and flow conditions in the gravel-bed rivers.

The development of a scour prediction formula that has been developed specifically for gravel-bed rivers is of immediate importance and use to DOT and practicing engineers. Because of the lack of formulas for predicting the scour depth around hydraulic structures in gravel-bed rivers, DOT and practicing engineers resort to using formulas, which have been developed for sand-bed rivers and subsequently correcting their predictions with empirically derived coefficients. These formulas cannot fundamentally provide accurate predictions for the scour depth in gravel-bed rivers and even their corrected estimates are riddled with uncertainty.

◆ **Project 25-55**

Quantifying the Contribution of Vehicle Emissions to Local Air Quality

Research Field: Transportation Planning
Source: AASHTO Standing Committee on the Environment
Allocation: \$700,000
NCHRP Staff: William C. Rogers

Accurate estimation of vehicle emissions and their contribution to overall air quality are essential components in air quality assessments of proposed transportation projects. The combination of ambient air quality measurements and use of modeling tools provides the best available framework to help improve the understanding and measurement of motor vehicle contributions to local air quality. Air quality emissions and dispersion models have an important role in the established regulatory policy structure. This role is to help ensure that federally supported transportation projects will not have a significant effect on the human environment within the context of the National Environmental Policy Act of 1969, as amended, and not adversely affect compliance with National Ambient Air Quality Standards as set forth in the U.S. Environmental Protection Agency's Transportation Conformity Regulations. Given the prominence of model predictions in the decision-making process, it is essential that outcomes from the traffic/emissions/air dispersion model chain remain credible. Recognizing the important role of these models in the decision making process and the need for credible results, the proposed research will establish a range of variability in model predictions, which can ensure confidence in the modeling chain process.

Research similar to that under consideration has been completed by TRB—*ACRP Report 71: Guidance for Quantifying the Contribution of Airport Emissions to Local Air Quality* and *NCFRP Report 4: Representing Freight in Air Quality and Greenhouse Gas Models*.

A Near-Road Measurement Data Synergy Study sponsored by the Transportation Pooled Fund (TPF) partners is currently under way to identify and characterize the best available near-road monitoring sites to use for future model evaluation initiatives as recommended in this research. The TPF research will develop a database that contains the highest measurements from the EPA near-road monitoring network, along with coincident measurements from other regional monitoring sites and readily available traffic activity data.

Research has also been completed in the past for different sets of mobile source emission models and highway air dispersion models. The proposed research will include the most recent models that have not been evaluated in previous research. Test case applications of the models combined with field measurements will serve as a guide for completing assessments for similar transportation facilities. The proposed research will improve the confidence that analysts and decision makers have in the results obtained from the air quality modeling chain in characterizing project impacts.

The objective of this research is to evaluate models, modeling techniques, and ambient measurements to comprehensively understand and explain vehicle emissions contributions to local air quality.

◆ Project 25-56

Methods for State DOTs to Reduce Greenhouse Gas Emissions from the Transportation Sector

Research Field: Transportation Planning
Source: AASHTO Standing Committee on the Environment
Allocation: \$500,000
NCHRP Staff: Lori L. Sundstrom

This research will identify specific efforts and strategies to reduce transportation sector greenhouse gas (GHG) emissions that are within state DOT control and provide methods for estimating and monitoring benefits and costs of these efforts.

Increasingly, state DOTs are being asked to reduce GHG emissions from the transportation sector. These requests are coming from the public, state governments (e.g., Governors' offices), and from FHWA (e.g., new requirements for addressing GHG emissions in NEPA, potential national GHG performance measures). However, many of the strategies available to reduce GHG emissions from transportation are not under state DOT control (such as vehicle fuel economy standards and low carbon fuel standards). Many states lack the tools to quantify GHG emissions and it is often unclear what specific actions DOTs can take to reduce GHG emissions and the cost and benefits of those actions.

The research will give state DOTs the tools to evaluate the cost-effectiveness of potential GHG reduction actions and allow DOTs to make informed decisions about how to meet current and future state and federal GHG reduction goals, targets, and requirements. It will look beyond enterprise efforts related to state fleets and buildings to identify specific strategies that may include EV infrastructure, travel demand management, mode shift, projects to reduce miles traveled, or other efforts influenced by state DOTs.

A vast body of work around transportation and GHG emissions has been developed that ranges from in-depth discussion of specific strategies, such as installing solar panels in the right of way, to integrating GHG mitigation into planning, to understanding lifecycle emissions from construction practices. A variety of tools and methods have been developed to calculate emission reductions in the transportation sector, e.g., The Energy and Emissions Reduction Policy Analysis Tool (EERPAT), which evaluates a wide variety of policy options at the state or county level. However, efforts to apply those results to specific transportation stakeholders, including state DOTs, are lacking. State DOTs need solid information about what they can do to reduce GHG emissions from the transportation sector. This research will build upon the existing body of research by focusing the information to actions state DOTs can take to reduce emissions.

The research approach may include (1) a State of the Practice report that identifies current state DOT practices and existing tools and information, (2) a comparison of tools and strategies to reduce GHG in terms of state DOT authority, (3) identification of challenges to state DOTs for reducing transportation GHG emissions, (4) creation of a dynamic tool to evaluate costs and benefits of various GHG reduction strategies pre and post implementation, and (5) training state DOT staff to use the product(s), e.g., a webinar.

The most urgent need for this information is to meet new requirements from FHWA to evaluate GHG emissions in NEPA documents. FHWA does not require GHG reductions associated with this effort, but state DOTs expect other stakeholders to make this request. Another benefit is to support the increasing number of states with state GHG reduction goals that they are not on track to meet. Finally, FHWA recently proposed a GHG performance measure; setting reduction targets, and working to achieve them, will require all state DOTs to better understand which GHG mitigation options they can directly implement or affect.

Without this research, state DOTs will be less able to discuss the context of the GHG emission results now required in NEPA documents. Should FHWA finalize a GHG performance measure, without the information and tool from this research, states will face substantially more work and uncertainty in setting goals and making decisions on how to meet them. Finally, state DOTs will continue to build transportation projects, but without an improved understanding of how to reduce GHG emission through their projects, and programs will miss opportunities for reductions and could even unknowingly take actions that are counterproductive.

PROJECTS CONTINGENT ON THE AVAILABILITY OF FUNDS

◆ Problem No. 2018-B-05

Wood Chips Colonized by “Wild” Fungi for Stormwater Petroleum Reduction

Research Field: Transportation Planning
Source: AASHTO Standing Committee on the Environment
Allocation: \$400,000
NCHRP Staff: Lori L. Sundstrom

Petroleum generated hydrocarbons are present in stormwater runoff at most transportation facilities, and reducing their levels is a common requirement in National Pollutant Discharge Elimination System (NPDES) permits. Specific pollutants include polycyclic aromatic hydrocarbons (PAHs), gasoline, diesel and heavy oil; benzene, toluene, ethylbenzene, total xylenes (BTEX); and hexane. Such hydrocarbons are often implicated in negative impacts on aquatic and terrestrial species and ecosystems, and may instigate expensive remediation projects. A greater focus on those PAHs by resource and regulatory agencies can be expected in the near future.

Effective and inexpensive techniques for removing this class of pollutants are needed. Many best management practices (BMPs) offer strategies to reduce export of these pollutants through actions such as “settling out” of hydrocarbons attached to solids but fail to actively eliminate the hydrocarbons. Persistent forms of hydrocarbons may reside and even accumulate in such BMP designs. The accumulation of petroleum and petroleum byproducts in BMP filter media complicate the disposal of the media when its effectiveness wanes. By developing a BMP that is effective at both trapping and decomposing petroleum hydrocarbons in stormwater, both issues can be addressed.

One technique that has demonstrated actual breakdown of petroleum hydrocarbons is mycoremediation. Mycoremediation is a form of bioremediation that utilizes fungi for various treatment objectives. Numerous studies have demonstrated the potential of using fungi to treat PAHs, gasoline, diesel and heavy oil, BTEX, naphthalene, and hexane. Generally, mycoremediation requires extensive preparation of a substrate (e.g., straw or wood chips) for the fungal food source and habitat and seeding with select fungal species. However, mycoremediation with waste wood chips, colonized by naturally occurring “wild” fungi, may offer petroleum remediation benefits without the standard preparation and seeding practices. Additionally, the low cost and feasibility of using waste wood chips allows for broad scale implementation of this petroleum treatment in much of the nation. Any location where robust decomposition of wood chip occurs should be appropriate to accomplish levels of petroleum remediation.

The methods fungi employ to breakdown petroleum hydrocarbons are not completely known. Much of the research points to the mechanisms for breaking down lignin, which contains complex carbon and hydrogen bonds that share some similarities with petroleum hydrocarbons. However, few studies have examined the potential of decomposing wood chips colonized by wild local fungi for remediating petroleum. In most ecosystems, fungi are the principal decomposers of wood and specifically the predominant decomposers of lignin. Considering that any decomposing wood chip pile is experiencing breakdown of lignin, it seems plausible these breakdown mechanisms may apply to the carbon-hydrogen bonds referenced in petroleum mycoremediation literature. Even if wood chips colonized by wild fungi remediate fewer hydrocarbons than standard mycoremediation practices, which often target high levels of petroleum contamination such as oil spills, they may remediate the generally lower levels of petroleum found in transportation facility stormwater runoff.

Utilizing wood chips colonized by wild fungi is significantly more cost effective and feasible than the standard mycoremediation practices. As mentioned above, these standard practices entail extensive preparation of the wood chips and fungal spawn. In contrast, applying non-inoculated wood chips primarily requires obtaining and placing wood chips at appropriate locations and depths.

Many transportation-related activities and agencies generate waste wood chips or have economical access to waste wood chips, further increasing feasibility and reducing costs. As opposed to generating or purchasing expensive wood chips, waste wood chips would constitute the source material.

The objectives of the research are to:

1. Test and establish the petroleum hydrocarbon reduction efficacy of wood chips colonized by naturally occurring wild fungi and determine the effect of various design and site factors on performance over a range of conditions typical of transportation facility stormwater runoff.
2. Develop guidance on the use, limitations, design, and implementation of wild colonized wood chips in treating petroleum hydrocarbons in stormwater. The guidance is intended to be a practical manual for those who select and design stormwater management facilities. It will be broadly applicable and not limited to a narrow range of conditions or geography.

Achieving the project's objectives involves the following tasks:

Task 1: Conduct a survey and synthesis of existing literature related to establishing practical mycoremediation procedures for treating hydrocarbons with wood chips, as well as monitoring for potential negative impacts from the wood chips.

The survey should focus on the ideal size and species composition of the wood chips; ideal hydraulic residence time of stormwater in the wood chips; ideal depth, width, and length of wood chip placements; the effective lifespan of wood chips; the effects of environmental factors (climate, underlying soil types, etc.) on the above characteristics; and the leaching of pollutants, such as nitrates, from the wood chips. The synthesis report should cover the preceding elements and include a gap analysis of information required to complete the project.

Task 2: Design and implementation testing of wild fungi colonized wood chips.

Design considerations should include (1) using actual stormwater to field test wood chips colonized by wild fungi (initial testing of the monitoring site may be required to ensure measurable levels of petroleum hydrocarbons are present); (2) ensuring clear comparisons of treated and non-treated stormwater, such as influent to effluent comparisons; (3) conducting as needed statistical tests and sample size analyses to obtain statistically robust data; (4) conducting field and possible laboratory testing to address the information gaps in Task 1 (testing will establish and confirm the capabilities of wood chips to manage stormwater runoff in varying facilities runoff situations); and (5) analyzing data collected in Tasks 1 and 2.

Task 3: Develop guidance on the use of wood chips colonized by wild fungi in treating petroleum hydrocarbons in stormwater runoff at transportation facilities.

This guidance will include (1) factors used to determine when and where wood chips are appropriate for stormwater treatment; (2) design criteria for wood chips, taking into account varying facility operations and climate; (3) criteria addressing wood chip characteristics, layer thickness, etc.; and (4) techniques and information required to estimate the water quality performance of wood chips for project specific situations.

The audience for this research is stormwater designers who evaluate, select, and design stormwater BMPs; and DOT environmental staff who ensure DOT projects meet environmental permit requirements and who negotiate stormwater management criteria with regulatory agencies. Results of the research will be disseminated through AASHTO or FHWA webinars, focused articles in stormwater trade publications, and presentations at venues such as Transportation Research Board annual or midyear meetings, and the National Hydraulic Engineering Conference.

◆ **Problem No. 2018-D-08**

Coastal Roadway Embankment Vulnerability to Sea-Level Rise and Increased Storm Severity

Research Field: Materials and Construction
Source: Rhode Island
Allocation: \$600,000
NCHRP Staff: Lori L. Sundstrom

An increasing number of coastal roads will become exposed to more frequent flooding brought about by ongoing sea level rise and increased storm severity. Coastal roads have well-constructed roadbeds, but, more often than not, the embankment material consists of native erodible sand or silty clay. Embankment slopes can be strengthened against overflowing water with well-maintained grass, turf reinforcement mats, or even stone revetments; but landward rushing storm surge, sometimes combined with waves, can destroy roads as happened during Hurricane Ivan in 2004.

Present technology can predict coastal storm surge levels and the inland extent of flooding with reasonable accuracy. Unfortunately, it is not possible to make reliable estimates of roadway embankment resiliency in terms of overflowing water depth, embankment material and geometry, and any installed slope protection. If waves are also present, the situation is even more uncertain.

Engineers and planners must have tools to assess the vulnerability of coastal roads during projected flooding exposure related to sea-level rise and the increasing intensity and frequency of coastal storms. Such a tool should provide an estimate of tolerable overtopping water depth that can be withstood for the particular embankment composition and installed slope protection. Critical roads with low expected embankment resiliency should be identified as remedial priorities. However, it may be possible to increase the resiliency with additional embankment slope protection to postpone the likely need to elevate the roadway or re-route the road. Combining an embankment resiliency assessment methodology with probabilistic estimates of storm surge and other societal factors will provide a means for prioritizing roadway maintenance and upgrading decisions.

A review of the current literature indicates a growing awareness of coastal highway vulnerabilities, but also indicates a lack of research linking coastal roadway resiliency to overtopping erosion and failure. Moreover, it appears that concerns regarding this research deficiency would benefit greatly from information being produced from work done regarding levee and dam overtopping. The literature suggests the need for a well-designed laboratory study of roadway embankment overtopping, guided by analysis of the literature on levee and earthen-dam overtopping. Such a study necessarily involves considerations from several expertise areas: hydraulic, geotechnical, meteorological, plant science (notably regarding grasses), and erosion-protection methods.

The research may be conducted in phases, with Phase 1 including conducting a suite of full-scale laboratory model experiments of roadway embankment overtopping by flood. The tests will include a variety of embankment materials combined with different slope protection, thus covering a broad range of existing coastal highway situations. Testing scenarios will be developed at workshops attended by State and Federal highway officials. Methods for predicting tolerable overtopping will be developed as a function of the important, easily quantified physical parameters. A practical manual will be prepared that clearly illustrates how DOT engineers and planners can make assessments of roadway vulnerability.

Phase 2 may include additional full-scale testing of either additional geometry/material combinations or reproducing previous tests with the addition of waves. Some tests will examine the benefits of retro-strengthening existing roadway embankments to better withstand expected increased overtopping.

Sea-level rise, and concerns about storm severity, over the past ten years have already announced myriad problems for vital coastal infrastructure. Ultimately, some roadways will need to be elevated or re-located in order to continue functioning as intended. These costly decisions necessitate a tool for assessing the vulnerability of existing roadway embankments in order to prioritize actions and funding requests. Being able to increase embankment resiliency to overtopping by a known amount with additional embankment slope protection can

extend the functional life of some roadways during a time when the prospect of storm overtopping becomes more certain.

Lack of such an assessment tool will hinder the ability of engineers and planner to plan effective strategies for dealing with highway-related impacts associated with sea-level rise. Prioritization of construction and maintenance activities will not have a rational basis for assigning damage risk for reaches of coastal roadways.

The research will be directly usable by State DOT engineers and planners by providing a valid and rational justification for actions aimed at decreasing sea-level rise impacts. Decision makers will be able to weigh consequences of their actions along with all the other elements that must be considered.

◆ **Problem No. 2018-F-07**

Improving the Guidelines for Inspection and Strength Evaluation of Suspension Bridge Cables

Research Field: Maintenance
Source: New York
Allocation: \$750,000
NCHRP Staff: Waseem Dekelbab

Because of the complexity of the technical information presented in *NCHRP Report 534*, the FHWA published a *Primer for the Inspection and Strength Evaluation of Suspension Bridge Cables* in May 2012 to supplement *NCHRP Report 534*. The Primer, with much of the information taken directly from *NCHRP Report 534*, offers an initial resource for agencies planning and performing inspections, metallurgical testing, and strength evaluations of suspension bridge main cables. The Primer also presents “BTC Method for Evaluation of Remaining Strength and Service Life of Bridge Cable” in the appendix as an alternative methodology to that provided in the *NCHRP Report 534*, for the evaluation of bridge cable remaining strength and its residual life. In addition, the Primer states that the AASHTO LRFR method is not yet applicable to the rating of suspension bridge cables since LRFR calibrations have not been performed to date for suspension bridges. The other concern is that the current LRFR calibration is designed for bridges with dead load to live load ratios generally not higher than about 2 to 1. For major suspension bridges, however, the dead loads may be higher than the live loads by a factor of 5 or more.

The objective of this research is to improve the current industry practice in inspection and strength evaluation of existing suspension bridge main cables in the following areas: (1) optimization of the main cable opening frequencies and wire sampling methodologies to minimize the potential damage to existing cable wires; (2) resolving the discrepancies in evaluating the main cable remaining strength when using alternative methods such as the BTC Method and the Random Field-Based Approach to increase the confidence in predicting the main cable remaining strength; (3) adopting a reliability-based evaluation methodology consistent with LRFD and LRFR philosophy to verify that the cable target failure probabilities are not exceeded with the consideration of the main cable remaining strength as well as the applied load effects; and (4) advancing the state-of-the-art NDE and SHM techniques to reduce our dependence on cable opening and wire sampling in main cable inspection and strength evaluation.

◆ **Problem No. 2018-G-09**

Quantifying the Impacts of Corridor Management

Research Field: Traffic
Source: Virginia
Allocation: \$450,000
NCHRP Staff: Lori L. Sundstrom

The integration of transportation planning and land use is critical to ensuring sustainable corridor functionality and surrounding growth. Corridor management is an important transportation planning activity that integrates transportation and land development and coordinates state DOT and local decision-making. More specifically, corridor management—in its full form—coordinates the planning, design, and operational characteristics of a highway or thoroughfare with the local street network and the layout, access, and inter-connectivity of adjacent land development. Corridor management yields results that demonstrate the impact of utilizing a coordinated, comprehensive approach throughout the transportation planning and land development processes. However, it can be difficult to assess and *quantify* the impacts of corridor management in a manner that persuades state and local officials that they should invest time and money into developing corridor management plans and processes in lieu of utilizing their current independent approaches.

Many states have designated corridors of significance, but long term planning for the management of these corridors is lacking. The absence of such planning might relate to the fact that there are no tools focused on this topic. This research project proposes to fill this critical gap by quantifying the impacts associated with corridor management. This quantification would support improved, proactive planning and altering of inefficient practices.

FHWA's Integrated Corridor Management (ICM) program is strictly directed toward *operations and performance* on corridors using technology and ITS. This research proposal is focused on corridor management as a proactive transportation/land use *planning* activity.

The objective of this research is to evaluate and, where possible, quantify the impacts of corridor management. As is evident from the literature review, there is often little or no follow up from the step of implementing corridor management to the point of quantifiably measuring the impact that such techniques have on the businesses, travelers, land values, and the long-term sustainability of a corridor. This project will assemble and develop comparative data—both quantitative and qualitative—for corridor management components and attributes such as access density, median usage, signal spacing, crash rates, development connectivity, value of improvements, business stability, land values, and aesthetics. Obtaining this type of data will require data collection specific to selected corridors. Some of the data may already be available or collected by government agencies; other parts of data will require detailed research of historic records and conditions and interviews with local planners and engineers.

◆ **Problem No. LTPP-1A5**

LTPP Data Analysis: Develop Tools to Improve Accuracy of Traffic Loading Data Collection

Research Field: Maintenance
Source: Federal Highway Administration
Allocation: \$350,000
NCHRP Staff: Lori L. Sundstrom

There is a need in the highway community to know how accurate and consistent weigh-in-motion (WIM) systems are for collecting traffic loading data. This data is a critical input in pavement and bridge designs and is used for making transportation and freight planning decisions, and in highway safety investigations. There are many potential sources of error in WIM measurements. Currently, it is nearly impossible for the traffic data collectors to evaluate the relative influence of each source. This leads to diminished WIM system performance and lower quality WIM data.

For over a decade, the LTPP program has collected a massive amount of consistent, high-quality WIM data, along with information about the performance of WIM equipment, including WIM validation and calibration data from 24 LTPP SPS test sites across the United States. This unique data set provides the opportunity to develop more advanced WIM tools to help state highway practitioners in pavement smoothness evaluation, WIM site selection, WIM sensor selection or replacement, WIM calibration procedures and frequency, and WIM data quality acceptance. These tools could help minimize WIM measurement errors related to temperature and seasonal effects, vehicle speed, changes in truck populations, data sampling frequencies, system age, and other factors related to WIM scale technology.

The objective of this research is to develop the next generation of tools and procedures for characterizing and managing the variability and bias in WIM measurements through more effective site selection, WIM sensor technology considerations, effective WIM calibration, and quality control checks of the data.

Now is the time to examine the lessons learned and to improve/develop new tools for highway agencies to collect reliable WIM data. These tools will allow for more effective WIM data quality assessment and more efficient, data-driven WIM calibration scheduling. Better-quality WIM data will lead to more accurate and cost-effective pavement and bridge designs, more informed transportation and freight planning decisions, and more insightful highway safety investigations.

◆ **Problem No. LTPP-2A8**

LTPP Data Analysis: Significance of As-Constructed Asphalt Pavement Air Voids to Pavement Performance

Research Field: Materials and Construction
Source: Federal Highway Administration
Allocation: \$425,000
NCHRP Staff: Lori L. Sundstrom

FHWA is promoting an initiative to increase the level of compaction of asphalt concrete (AC) mixtures to 94% of maximum theoretical density. FHWA's Increased In-Place Pavement Density initiative enables highway agencies to experiment with construction techniques and technologies to increase the in-place density of asphalt, which can result in pavements that are more durable. This action is based on the axiom that “a 1% reduction in-place air voids can increase service life by at least 10%.” The potential significance of the effect on ultimate pavement performance of compaction during AC mixture construction and the fact that this cost is much less than resulting maintenance, preservation, and rehabilitation costs to address reduced pavement life, are the bases for interest in this subject. To date, the best evidence of the impact of AC mixture compaction on potential pavement performance comes from controlled laboratory studies.

The objective of this research is to use mainly LTPP data, supplemented with other data sources, to examine the following issues: (1) evaluate the use of LTPP data for determining the effect of as-constructed air voids/degree of compaction on performance of AC pavements; (2) evaluate the effect of air voids/degree of compaction on AC mixture stiffness properties; (3) assess the viability of using uncontrolled field data in assessing the effects of degree of compaction on the resulting performance of AC mixtures; (4) investigate the significant differences in how compaction efficiency is measured; (5) provide recommendations on the formation of a field study to provide direct evidence on the effect of air voids/degree of compaction on AC pavement performance, based on limitations, if any, of currently available field data; and (6) provide recommendations on changes to national standards on AC mixture construction, primarily those related to compaction and related AC mixture properties suitable for pavement construction quality control purposes.

The urgency of this research is based on FHWA's initiative and potential State changes to specifications and practices. FHWA is trying to find support for this initiative from analysis of field data; however, from predominantly lab data, increase in the compaction standards appear warranted. If this problem statement is not funded, it seems clear that States will revise their specifications and practices with very limited field verification. A non-conclusive finding from this research based on field data may or may not influence future FHWA efforts.

◆ **Problem No. LTPP-2B8**

LTPP Data Analysis: Relationships between Material Properties Determined in Field and Laboratory for Untreated Materials

Research Field: Materials and Construction
Source: Federal Highway Administration
Allocation: \$300,000
NCHRP Staff: Lori L. Sundstrom

Currently, pavement designs are primarily related to structural rehabilitation treatments or reconstruction of existing pavements. Past and current design techniques require characterization of the in-situ elastic modulus properties of the materials contained in the pavement structure. The two primary ways to characterize these material properties for in-situ unbound material layers are through the interpretation of deflection measurements or laboratory tests on material samples obtained from the field. It has been conclusively established that the results from backcalculation of deflection measurements do not always match the results from laboratory tests on samples obtained in the field, even when comparable stress states are matched. Evidence suggests that the way field samples are prepared and tested in the laboratory can affect modulus-based test results as compare to in-situ tests.

During construction of new and reconstructed pavement structures, field compaction control of unbound materials has historically been based on density measurements as a percentage of laboratory determined optimum. Some types of newer compaction equipment use a modulus-based feedback mechanism to control field operations. The relationship between density, maximum density, elastic modulus, resilient modulus, backcalculated modulus, and moisture content as it applies to pavement design, field compaction, and pavement performance justifies further research.

The primary objective of this research is to establish relationships between material properties determined through field tests and those from laboratory test on field samples contained within the LTPP database for pavement design and performance prediction purposes.

The objectives of this research are to: (1) establish relationships for resilient modulus among samples prepared by the following three methods: lab mixed-lab compacted, field mixed-lab compacted and field mixed-field compacted; (2) establish relationships among other material properties (Atterberg Limits, LA Abrasion, sand equivalent, soundness, gradation, moisture content, etc.) for samples obtained from aggregate stockpiles at the materials production site, from haul vehicles and from the pavement before and after compaction; (3) establish relationships, if any, from DCP and FWD backcalculated modulus field data; and (4) establish the impacts of the differences in field and laboratory determined unbound material properties on MEPDG pavement performance prediction models.

◆ **Problem No. LTPP-3A9**

Assessment and Simplification of Pavement Environmental Effects Models on Pavement Performance

Research Field: Materials and Construction
Source: Federal Highway Administration
Allocation: \$350,000
NCHRP Staff: Lori L. Sundstrom

Studies conducted in Arkansas, Idaho, Minnesota, New Jersey, and Ohio report issues in matching the predictions from the Enhanced Integrated Climatic Model (ECIM) for moisture contents with field observations. LTPP has recently encountered issues in trying to translate the SHRP PG binder grades designations to locations outside of the continental United States using algorithms developed in North America. FHWA is also using simplified versions of Mechanistic-Empirical Pavement Design Guide (MEPDG) pavement performance prediction models to predict changes in the National Highway System based on HPMS data inputs and very coarse climate inputs to the simplified models.

The overall objective of this project is to develop simplified models of climate impacts on pavement performance-prediction models that can be implemented by local, state, and federal agencies in their asset and pavement management systems. Some of the issues to be investigated include: (1) evaluation of the impact of using the complete suite of current Modern-Era Retrospective Analysis for Research and Applications (MERRA) grid data that includes direct use of solar radiation inputs to predict pavement temperature, versus use of empirical relationships embedded in applications like the MEPDG and LTPPBind; (2) evaluation of the impact of using MERRA data for civil engineering applications that require hourly climate inputs; (3) evaluation of the use of MERRA data in calibration of the unbound material models used in the MEPDG; and (4) recommendations on the use of MERRA data in each of the evaluated engineering applications. If the MERRA 2 data set is available at the time of study, recommendations on the potential impact and difference of approach in using the two data sets (MERRA and MERRA 2) will be evaluated.

◆ **Problem No. LTPP-3C4**

LTPP Data Analysis: Mining LTPP Data to Develop Guidelines on Temporal Aspects of Pavement Performance Monitoring Measurements

Research Field: Maintenance
Source: Federal Highway Administration
Allocation: \$450,000
NCHRP Staff: Lori L. Sundstrom

The LTPP Seasonal Monitoring Program (SMP) was based on further discovery of the influence temporal changes in pavement structural characteristics. The primary measure of change in pavement structural characteristics was deflection data from falling weight deflectometers (FWDs). In an attempt to explain the observed temporal changes in FWD measurements, LTPP SMP sites were instrumented to measure local weather and subsurface moisture and temperature states. To date, the full potential of LTPP FWD and corresponding pavement-state data has not been fully examined. In addition to monthly FWD measurements on LTPP SMP test sections, LTPP collected seasonal data on longitudinal pavement profile on the SMP test section. In July 2013, LTPP implemented a program to measure diurnal changes in longitudinal profile on jointed PCC test sections in response to recommendations from industry. The results of some published findings and unpublished findings internal to the LTPP program show that on some LTPP jointed Portland cement concrete (PCC) test sections, temporal variations on the order of a few hours during a single day can have significant impacts on the International Roughness Index (IRI) computations from longitudinal pavement profile measurements, which can be translated to how highway agencies perform smoothness measurements for construction quality control and determine construction-related pay factors. There is a need to perform a formal mining of the rich base of time-based pavement performance measurements in order to refine current standards and guidelines on how to properly account for temporal variations in measured pavement properties.

The objective of this research is to refine current guidelines on performance of FWD and longitudinal profile field measurements that properly account for daily and seasonal variations in pavement condition and response. At a minimum, the guidelines on performance of FWD should consider the following: (1) frost-thaw issues in deep-freeze and multiple freeze-thaw climate zones; (2) frozen, partially frozen, and unfrozen subsurface pavement layers; (3) time and method to measure load transfer efficiency; (4) how and how much warping and curling affect basin testing on jointed PCC pavements; and (5) the influence of different pavement base and sub-base layer types (material and thickness, bonding conditions) and other features, including shoulders and joint types in the temporal changes of both flexible and rigid pavements.

◆ **Problem No. LTPP-6B4**

LTPP Data Analysis: Consequences of Deferred Treatment of Pavement Preservation Treatment Placement on Asphalt Concrete, Portland Cement Concrete and Composite Pavement Structures

Research Field: Maintenance
Source: Federal Highway Administration
Allocation: \$425,000
NCHRP Staff: Lori L. Sundstrom

Pavement preservation represents a proactive approach to maintaining and extending the lives of existing highways. A pavement preservation program consists primarily of three components: preventive maintenance, minor rehabilitation (non-structural), and some routine maintenance activities. Within the pavement community, it is widely believed that pavement preservation applications are an effective approach to extending a pavement's service life. Given the current economic environment, most state DOTs are now embracing the pavement preservation philosophy to utilize more cost-effective techniques to better serve the public. However, the consequences of deferred pavement treatment have become an increasing issue in debates over allocation of dwindling budgets for pavement related transportation infrastructure.

NCHRP Project 14-38, "Guide for Timing of Asphalt-Surfaced Pavement Preservation," initiated in 2016, focuses on using a cost-benefit approach to determine the best timing of pavement preservation treatments on asphalt surface pavements, but it will not examine PCC preservation treatments, and it will not look at global optimization issues from the viewpoint of a constrained resource network.

The objective of this research is to provide a tool to practitioners on the consequences of deferred corrective treatments on AC, PCC, and AC over PCC composite pavement structures (i.e., beyond the scope of NCHRP Project 14-38). Asset managers have a responsibility to the public to provide service in a cost-effective manner, and we are now in the age of performance management that requires measuring and reporting performance of the National Highway System. This work includes impacts on vehicle operating costs, sustainable cost accounting, life cycle accounting, and life cycle cost accounting regimens.