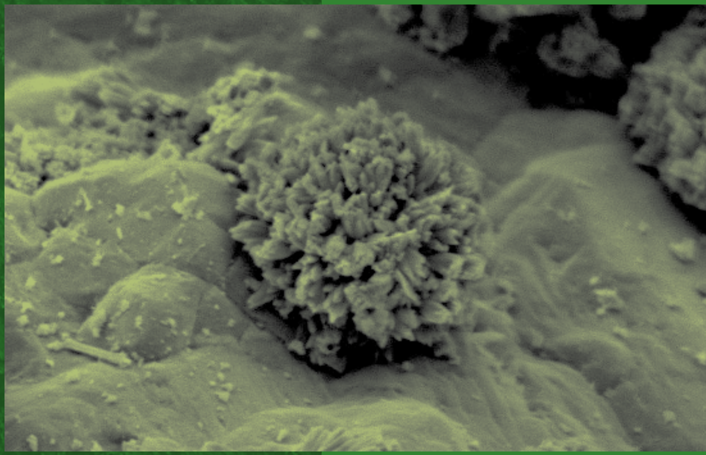
Exploratory Advanced Research Program

Research Associates Program 2014

EXPLORATORY ADVANCED RESEARCH



U.S. Department of Transportation

Federal Highway Administration

Notice

Quality Assurance Statement

Cover photos show a strand splice detail for beam connection (left), part of a research objective to critically assess the applicability of a tensile test method for ultra-high-performance fiber-reinforced concrete; and the nucleation of ettringite mineral in the interfacial transition zone (right), part of a research objective to develop inorganic curing compounds to address the shortcomings of current organic membrane forming curing compounds.

Contents

The Research Associateship Program

Since 1954, the National Research Council (NRC) has conducted the Research Associateship Program (RAP) in cooperation with sponsoring Federal laboratories and other approved participating research organizations. RAP provides highly skilled and exceedingly promising postdoctoral and senior scientists and engineers with opportunities to research problems that are compatible with the interests of sponsoring laboratories. RAP offers recent doctoral graduates opportunities for concentrated research with selected members of permanent professional laboratory staff and allows them to contribute to the overall efforts of the laboratories.

The Federal Highway Administration (FHWA) has participated in RAP since 1992. To supplement the expertise of permanent staff, FHWA's Turner–Fairbank Highway Research Center (TFHRC), through its Exploratory Advanced Research (EAR) Program, invites researchers with appropriate backgrounds to investigate specific problems on a short-term basis across a wide range of topics and disciplines.

NRC provides a process for selecting candidates on a competitive merit basis and subsequently for administration of the resident fellows during their tenures at FHWA. The process begins with a prospective FHWA adviser developing a proposed research opportunity. The adviser then coordinates with FHWA leadership to approve the opportunity and to forward the proposed research to NRC. All research opportunities require an abstract that relates to exploratory advanced research and that is of specific relevance to the FHWA research program. One of the significant benefits of this process is that it encourages interaction between government researchers and new researchers who are using cutting-edge approaches and research tools in their work.

RAP provides opportunities for FHWA's EAR Program to advance research methods used at TFHRC. Over the years, associates have researched topics as diverse as nano-additives for concrete and asphalt, alternative intersection and interchange design, and modeling to predict collisions based on driver behavior and environmental conditions.

The following pages contain summary descriptions of some of the research projects that the resident fellows have been involved in during their respective tenures at FHWA.

The EAR Program addresses the need for longer term, higher risk research with the potential for long-term improvements to transportation systems—improvements in planning, building, renewing, and operating safe, congestion-free, and environmentally sound transportation facilities. The EAR Program seeks to leverage advances in science and engineering that could lead to breakthroughs for critical current and emerging issues in highway transportation, that is, where there is a community of experts from different disciplines who likely have the talent and interest in researching solutions and who likely could not do so without EAR Program funding.

PROJECT: **Comprehension and Development of Nano-Additives to Judicially Improve the Interfacial Region in Concrete and Asphalt**

ASSOCIATE: Jose Muñoz

SCHOOL: University of Wisconsin–Madison

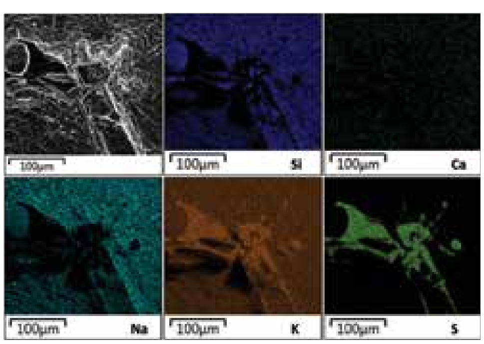
PERIOD: April 2010–March 2013

OBJECTIVE: To investigate how judicially applied coatings on the surface of the aggregates of different nano-additives can improve the interfacial region in concrete and asphalt.

ADVISER: **Jack S. Youtcheff,** Office of Infrastructure Research and Development

SUMMARY: Jose Muñoz examined a method to enhance the area of contact between cement-paste aggregates and asphalt aggregates, known as the *interfacial region*. This is one of the most vulnerable areas of concrete and asphalt, potentially affecting the overall performance of pavement. The durability of concrete is highly influenced by its pore structure, specifically a highly porous area known as the *interfacial transition zone* (ITZ). Large fractions of the microcracks occurring in concrete are associated with the ITZ; therefore, improving the strength of the ITZ could significantly improve concrete durability. Traditional approaches to the problem, involving the successive addition of different silicon or aluminum-based materials, have been inefficient and costly. Muñoz based his research on the theory that nanoparticles added as nanoporous films, and when judiciously placed on the aggregate surface, can greatly improve the ITZ and thereby the performance of the concrete. He investigated changes triggered by nanoporous thin films in the chemistry and morphology of the hydration products located at the aggregate–cement paste interface. Muñoz developed a model to determine two-dimensional spatial distribution of cement hydration phases and to study the aggregate–cement paste interface in concrete. In addition, Muñoz developed a new sol-gel synthesis (a method for producing solid materials from small molecules) to produce "nanoaluminosilicate" gels with a controlled silicon-to-aluminum ratio. Muñoz also studied the effect of these nanoaluminosilicate gels with different silicon-to-aluminum ratios on the hydration reaction of portland cement.

IMPACT: The development of new nano-additives, together with a new method for applying them in concrete, is expected to help create materials with less water and chloride penetrability, and higher mechanical strength and resistance to cracking. This is expected to lead to the creation of construction materials with improved characteristics and less energy demand for maintenance operations. The application of nanoparticles in concrete and asphalt, using dip- or spray-coating methods, offers several advantages when compared with the traditional addition of nanoparticles as powder additives. It is an easier and safer application method—fewer additives are required, which reduces costs—and the technology is already available. In addition, this technology can have a positive impact in locations with limited or marginal quality aggregate sources. For example, these nano-additives can be used to improve performance of currently marginal aggregates, such as natural aggregate with significant contents of clay minerals strongly adhered to their surface.



Backscattered electron images of a potassium sulfate crystal formed inside of a silica gel in the interfacial transition zone.

ONGOING RESEARCH: Muñoz continues to study the effect of the nanoparticles in concrete pore solution at early stages of hydration. In addition, he also performed research with the U.S. Army Engineer Research and Development Center to characterize the ITZ modified with nanoparticles.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Muñoz, J. F., Meininger, R.C., & Youtcheff, J. (2010). New possibilities and future pathways of nanoporous thin film technology to improve concrete performance. *Transportation Research Record, Journal of the Transportation Research Board, 2142,* 34–41.

Muñoz, J. F., Yao, Y., Youtcheff, J., & Arnold, T. (2011). Nanotechnology to improve aggregate performance. *National Research Council, Research Associateship Program Newsletter.*

Muñoz, J. F., Yao, Y., Arnold, T., & Youtcheff, J. (2013). Mixtures of silicon and aluminum oxides to optimize the performance of nanoporous thin films in concrete. *Cement and Concrete Composites.* Manuscript submitted for publication.

Munoz, J. F., Silva, J. M. S., Perry, L., Youtcheff, Y., & Sobolev, K. (2014). Interaction of amorphous nano-aluminosilicates with cement pore solution and the effect on the early hydration reaction of Portland cement. Accepted for publication in proceedings from *The Fifth International Symposium on Nanotechnology in Construction.*

Balachandran, C., Muñoz, J. F., Arnold, T., & Youtcheff, J. (2014). Potential application of surface enhanced Raman spectroscopy as a tool to study cementitious materials. Accepted for publication in proceedings from *The Fifth International Symposium on Nanotechnology in Construction.*

Muñoz, J. F., Li, E., & Youtcheff, J. (2014). Effect of the Si to Al ratio of nanoaluminosilicate gels on the hydration reaction of portland cement. In preparation.

PROJECT: **Developing New Vehicle–Tire and Contact Friction Models**

ASSOCIATE: **Emmanuel Bolarinwa**

SCHOOL: University of Birmingham

PERIOD: September 2010–

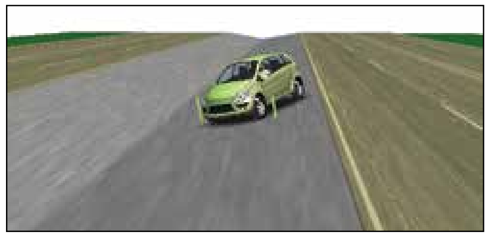
OBJECTIVE: To use a model-based approach for investigating the effect of tire–pavement contact friction on the safety performance of vehicles.

ADVISER: **James A. Sherwood,** Office of Infrastructure Research and Development

SUMMARY: The effective management of critical pavement surface characteristics, such as friction and texture, has been shown to help prevent or reduce the consequences of rear-end and run-off-the-road crashes. Although high-friction surfaces can lead to increased numbers of dry pavement rollovers, they also lead to fewer wet pavement run-off-the-road crashes and tend to have fewer crashes involving fatalities and serious injuries. For his research project, Emmanuel Bolarinwa implemented a model-based approach to investigate the effect of variations in vehicle– and tire–pavement friction on vehicle safety performance, such as stopping distances during braking. He considered the interactions among key crash causative factors and predicted vehicle performance and stability metrics. Bolarinwa examined a vehicle simulation package containing various values for pavement friction and texture inputs. For model verification, Bolarinwa obtained vehicle data and crash information from the Highway Safety Information System (HSIS) and the second Strategic Highway Research Program's naturalistic driving study. He then used the model to develop theoretical thresholds for pavement friction and texture inputs (i.e., the minimum values when crash rates have been found to increase at a significantly higher rate). Bolarinwa analyzed results from the simulation to extract vehicle performance and safety metrics as possible indicators of the onset of vehicle crashes for different vehicle types and a variety of road sections and geometries.

IMPACT: This research should lead to enhanced road safety, ensuring significant savings in cost and human lives by managing pavement friction. The research directly contributes to FHWA's strategic safety improvement program by predicting friction threshold values to determine conditions when a pavement should be investigated for maintenance intervention. Bolarinwa's research will lead to better characterization of the effects of a broad range of human, vehicle, and environmental factors on crash outcomes. It will also provide a basis for evaluating practices related to pavement surface material parameters and roadway geometry. FHWA will ultimately use the results of this research to develop new vehicle crash models, which will be of value to safety engineers working on state highway safety improvement programs. In addition, the results could be used to change pavement design standards to select the best pavements in terms of safety.

ONGOING RESEARCH: Bolarinwa will continue research into the development of theoretical threshold values for pavement friction and develop procedures for predicting stopping distances based on the friction of the pavement surface. The long-term goal is to reduce fatal and severe (incapacitating injury) crashes, by prescribing levels of pavement friction and macro-texture.



A simulation model for investigating vehicle behavior on a sloped terrain surface.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Uzunsoy, E., Bolarinwa, E., Olatunbosun, O., & He, R. (2014). Investigating Vehicle Behavior on a Sloped Terrain Surface.

Yang, X., Olatunbosun, O., Ramos, D. G. P., & Bolarinwa, E. (2013). Experimental investigation of tire dynamic strain characteristics for developing strain-based intelligent tire system. *SAE International Journal of Passenger Cars–Mechanical Systems, 6*(1), 97–108.

Bolarinwa, E. O., Mahadevaiah, U., Marzougui, D., & Opiela, K. S. (2012). The development of an enhanced finite element tire model for roadside safety hardware assessment. *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-Body Dynamics, 226*(3), 206–219.

Bolarinwa, E. O. (2014). *Material and geometrical characterization for FE tire modeling and simulation.* Paper presented at the 2014 Tire Technology Expo Conference, Cologne, Germany.

Bolarinwa, E. O. (2013). *Development of an FE tire model for vehicle crash simulations.* Paper presented at the 2013 Tire Technology Expo Conference, Cologne, Germany.

Bolarinwa, E. O. (2013). *Experimental investigation of vehicle behavior on a sloped-terrain surface.* Paper presented during the SAE 2013 World Congress and Exhibition, Detroit, MI.

Bolarinwa, E. O. (2012). *Role of tire testing in efforts to develop improved finite element models to support crash simulation.* Workshop on Improving the Modeling of Tire, Steering and Suspension Systems in Angular Crashes, FHWA Turner–Fairbank Highway Research Center, McLean, VA.

Bolarinwa, E. O. (2011). *The development of an enhanced finite element tire model for vehicle crash simulations.* Paper presented at the 30th Annual Conference on Tire Science and Technology, Akron, OH.

Bolarinwa, E. O. (2011). *Role of tire testing in efforts to develop improved finite element vehicle models to support crash simulations.* Paper presented at the 2011 Tire Technology Expo Conference, Cologne, Germany.

PROJECT: **Use of Inorganic Coatings as Curing Compounds**

ASSOCIATE: Jessica Silva

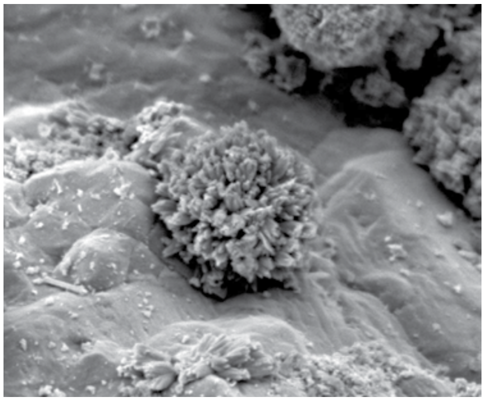
SCHOOL: University of Wisconsin–Madison

PERIOD: September 2012–December 2013

OBJECTIVE: To develop inorganic curing compounds to address the shortcomings of current organic membrane forming curing compounds.

ADVISER: **Jack S. Youtcheff,** Office of Infrastructure Research and Development

SUMMARY: Proper curing is a vital post-treatment process when constructing durable concrete pavements. This is because water loss by evaporation through exposed surfaces can result in mechanical or chemical deficiencies in the final surface of the concrete product. Existing membrane-forming curing compounds are widely used to form a physical barrier to prevent the migration of water during the first few hours of concrete placement; however, these membranes do not always form a continuous coating, may degrade after environmental exposure, and provide little protection of the concrete section at later stages of the pavement's service life. Jessica Silva's research project examined the use of inorganic curing compounds to address the shortcomings of current organic compounds. These inorganic curing compounds, prepared from metal-oxide materials, can react with the concrete surface to form durable coatings and hydration products. The compounds may also impart beneficial characteristics to the roadway and provide improvements to the pavement long after traditional membranes. Silva examined changes occurring to the air and mortar and mortar and aggregate interface, in addition to the porosity, density, and chemical makeup of the cement paste. Silva also ensured that the inorganic curing compounds under development would not adversely affect the concrete material. As part of this research project, Silva used a traceable element to better understand the effect of the compound as it penetrates the concrete.



Nucleation of ettringite mineral in the interfacial transition zone

IMPACT: This research could represent a paradigm shift in the world of curing compounds. In addition, if the material developed as a result of this research is not ultimately useful as a curing compound, it may still prove useful to enhance general concrete characteristics.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Silva, J. M. S., Youtcheff, J., & Arnold, T. (2013). Utilizing sol-gel nanoparticles in concrete curing to improve surfaces. *National Research Council Research Associateship Programs Newsletter,* 14–16.

Munoz, J. F., Silva J. M. S., Perry L., Youtcheff, Y., & Sobolev K. (2014). Interaction of amorphous nano-aluminosilicates with cement pore solution and the effect on the early hydration reaction of portland cement. Proceedings from *The Fifth International Symposium on Nanotechnology in Construction.* Accepted for publication.

PROJECT: **Utilizing Naturalistic Driving Data and Highway Safety Information System to Advance Highway Crash Data Modeling Concepts and Methods**

ASSOCIATE: **Kun-Feng Wu**

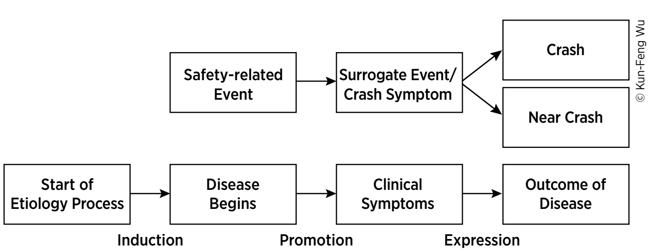
SCHOOL: Pennsylvania State University

PERIOD: July 2012–June 2013

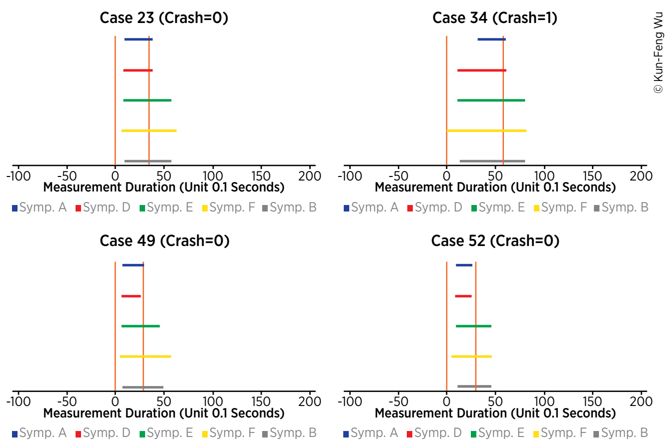
OBJECTIVE: To advance safety analysis using surrogate safety measures and improve the evaluation of intervention effectiveness.

ADVISER: **Craig P. Thor,** Office of Safety Research and Development

SUMMARY: Kun-Feng Wu's research project builds on 40 years of research concerning the development of crash surrogates for assessing traffic safety. The term *crash surrogate* refers to a crash or near-crash event, defined in this project by a set of driver or event attributes, driving environment, and kinematic variables. Researchers use crash surrogates because crashes are rare events, making it hard to draw statistically valid conclusions about contributing factors. Surrogate event counts can be used to predict the expected number of crashes and identify sites with promise for improvement by knowing the number of surrogate events at each intersection. Wu investigated a sequence of statistical tests with the overall goal of validating surrogate events and facilitating their use in enhanced safety analyses. Wu used raw naturalistic driving data, including vehicle kinematic, video, and location information, to produce sets of specific conditions that identify crashes and near crashes (i.e., surrogate events). Wu tested the procedure on a small 100-car naturalistic driving study dataset, conducted by the Virginia Tech Transportation Institute, with successful results. A second validation procedure compared these results with the number of crashes observed in HSIS data, a multistate database that contains crash, roadway inventory, and traffic volume data for a select group of States. Wu's research extends research already completed in the joint use of crash events and surrogate events in a structured framework. His research project specifically compared surrogate analyses of countermeasure effectiveness and sites with improvement potential to comparable HSIS studies. Wu applied the same methods to evaluate the Integrated Vehicle-Based Safety System dataset (an initiative designed to develop and field test an integrated safety system on light vehicles and commercial trucks). In addition, Wu expanded the procedures to include diagnostic analytical techniques borrowed from medical science. These statistical methods allow for a more accurate assessment of the presence of surrogate events.



A schematic that relates the crash progression process to the etiological process of disease progression.



The crash symptoms (horizontal lines) as they compare to manual identification of a crash-related event (vertical red lines). This exhibits the potential of surrogate measures to predict safety-related events based on kinematic and environmental factors.

IMPACT: Specific conditions for defining surrogate events could be further tested and studied through driving performance assessment and may ultimately lead to improved understanding of inappropriate driving behaviors, driver responses, roadway design, and operational deficiencies. In addition, crash surrogate studies could ultimately reduce the time needed to develop a sufficient sample size for analysis. These studies would enable researchers to develop models with greater prediction precision and understand the factors that contribute to crashes. Decreasing the time and increasing the precision of factors that contribute to crashes allow faster development and implementation of better countermeasures, thereby reducing crashes and potentially saving lives.

RESOURCES: The papers that resulted from this RAP research are outlined below.

Wu, K. F., Jovanis, P., & Thor, C. (2014). A systemic framework for studying traffic crash sequence. *Transportation Research: Part C.* Manuscript submitted for publication.

Wu, K. F., & Thor, C. (2014). *Utilizing naturalistic driving study data to study freeway rear-end crash sequences.* The 94th Transportation Research Board Annual Meeting, Washington, DC. Manuscript submitted for publication.

PROJECT: **Operational and Safety Analyses of Alternative Intersections/Interchanges Designs**

ASSOCIATE: **Nopadon Kronprasert**

SCHOOL: Virginia Polytechnic Institute and State University

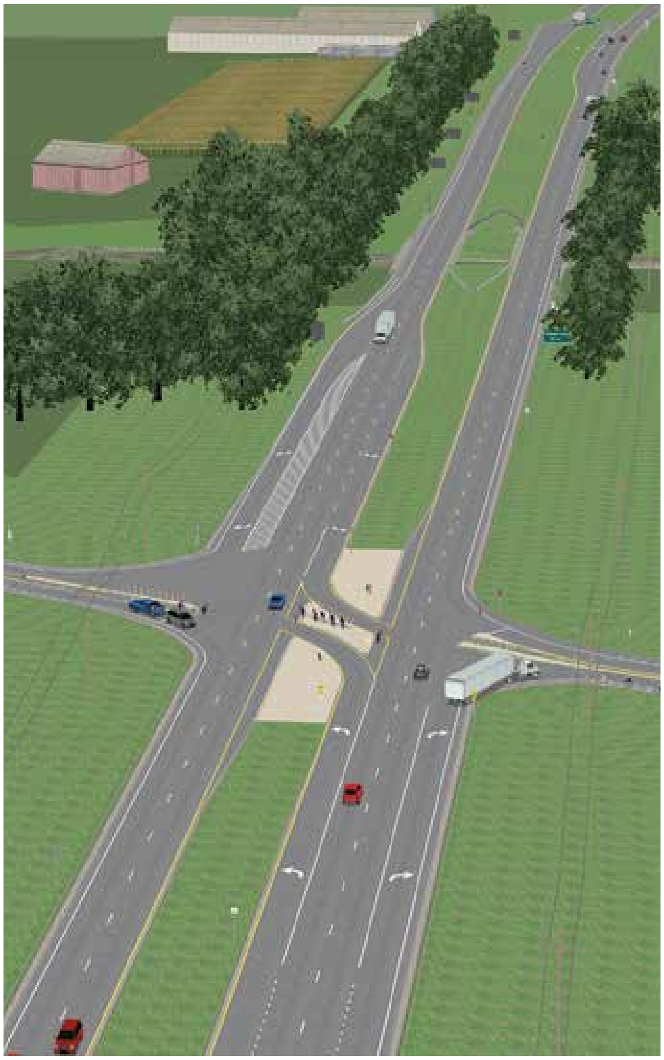
PERIOD: November 2012–April 2014

OBJECTIVE: To evaluate operational and safety impacts when implementing alternative intersection and interchange designs.

ADVISER: **Wei Zhang,** Office of Safety Research and Development

SUMMARY: Transportation and traffic professionals working on today's highway improvement projects face daunting pressures from the needs of different stakeholders to provide safe, efficient, and cost-effective intersections and interchanges. FHWA recently proposed several alternative intersection and interchange designs to improve the safety- and mobility-related issues across the Nation. These new intersections and interchanges include displaced left-turn, median U-turn, and restricted crossing U-turn intersections as well as the double-crossover diamond interchange. It is important to evaluate how efficient the new designs will be and to identify the traffic conditions that will deliver the best cost–benefit performance. In accordance with this objective, Nopadon Kronprasert's research project investigated operational and safety measures and evaluation procedures, analyzed proposed designs at different evaluation sites, and developed mathematical models for evaluating operational and safety measures for different intersection and interchange designs. Kronprasert used microscopic traffic simulation to model characteristics and behaviors of traffic systems and to evaluate the performance of alternative designs. This is a cost-effective method to compare different designs, predict potential impacts, replicate real-world phenomena, and provide valuable insights into the effects on operational and safety performance. Kronprasert conducted his research based on problems derived from real projects. As part of the technical support to State departments of transportation, he performed traffic simulation studies of three double-crossover diamond interchanges, three restricted crossing U-turn intersections, and six mini-roundabout projects.

IMPACT: As of October 2014, at least one restricted crossing U-turn and three mini-roundabouts Kronprasert worked on have been constructed and opened to traffic. Many of the performance predictions stated in his research are being verified in the field. The results will help analysts understand the relationships between



A screen capture of an intersection based on Nopadon Kronprasert's simulation input.

the features of alternative designs and their operational and safety benefits. The research will ultimately help practitioners to find the best course of action when implementing alternate designs and also will help highway engineers and the public understand the benefits and impacts.

ONGOING RESEARCH: Wei Zhang is continuing to conduct research on alternative intersection and interchange designs, building on Kronprasert's work. Zhang and Kronprasert are also collaborating on at least two more research papers.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

A screen capture of the simulation video created by Nopadon Kronprasert.

Krause, C., Kronpraset, N., Bared, J., & Zhang, W. (2014). Operational advantages of dynamic reversible left-lane control of existing signalized diamond interchanges. *Journal of Transportation Engineering.* Accepted for publication.

Zhang, W., & Kronprasert, N. (2014). The ABCs of Designing RCUTs. *Public Roads, 78*(2), 9–13.

Zhang, W., & Kronprasert, N. (2014). *Unlock DDI's capacity potential by implementing relaxed bowtie, superstreet, and quadrant road design at adjacent signal intersections.* Presented at the Second International Conference on Access Management, Shanghai, China.

Zhang, W., & Kronprasert, N. (2014). *Unlock diverging diamond interchange's capacity potential using relaxed bowtie design at adjacent signalized intersection.* Presented at the Transportation Research Board's Alternative Intersections and Interchanges Symposium, Salt Lake City, UT.

Zhang, W., & Kronprasert, N. (2014). *Crash prediction models for rural restricted crossing U-turn intersections.* Presented at the Transportation Research Board's Alternative Intersections and Interchanges Symposium, Salt Lake City, UT.

Zhang, W., & Kronprasert, N. (2014). *Mini-roundabout case studies.* Presented at the Transportation Research Board's International Roundabout Conference, Seattle, WA.

Zhang, W., Kronprasert, N., & Gustafson, J. (2014). *Unclog local network congestion using high-capacity mini-roundabouts: A feasibility study.* Presented at the Transportation Research Board's 93rd Annual Meeting, Washington, DC, and submitted for publication in *Transportation Research Record: Journal of the Transportation Research Board.*

Lochrane, T., Kronprasert, N., Bared, J., Dailey, D., & Zhang, W. (2014). Determination of mini-roundabout capacity in the United States. *Journal of Transportation Engineering, 140*(10).

Zhang, W., & Kronprasert, N. (2013). *Restricted crossing U-turn intersection design for improving safety and mobility at high-speed stop-controlled intersections.* Presented at the Road Safety and Simulation International Conference, Rome, Italy.

Zhang, W., Kronprasert, N., & Bared, J. G. (2013). *Visualizing the benefits of restricted crossing U-turn intersection design at high-speed two-way stop-controlled intersections.* Presented at the Transportation Research Board's Seventh International Visualization in Transportation Symposium, Irvine, CA.

PROJECT: **Integrating Driving Simulation and Other Behavioral Data: Assessment of Driver Behavior and Performance**

ASSOCIATE: Alicia Romo

SCHOOL: The University of Texas at El Paso

PERIOD: September 2013–

OBJECTIVE: To develop methods that will use data from various sources, such as driving simulator experiments, crash databases, and naturalistic driving studies, to gain comprehensive understanding about road-user behaviors.

ADVISER: **C. Y. David Yang,** Office of Safety Research and Development

SUMMARY: A high percentage of transportation incidents and vehicle crashes are caused by human errors. As a result, it is important to continue investing in research resources to gain a comprehensive understanding of human errors and to try to answer the question, "Why do drivers and travelers do what they do?" A number of different datasets have recently become available to analyze human errors; however, these datasets point in different directions within different areas of interaction. Alicia Romo's research project is focused on finding methods to combine data from different sources to gain better understanding about road-user behavior. During the first year, Romo conducted a comprehensive literature review and summarized information from more than 100 technical journals and reports about various methods to study road-user behavior and types of available behavioral data. Based on the information from this literature review, Romo has since developed a framework to categorize behavior data from various sources, such as crash databases, driving simulator experiments, field test vehicle studies, and naturalistic driving studies. Romo's research will show the benefit of using information from multiple data sources to study behavioral issues instead of relying on just one data source.

The relationship between research methods and impacting factors.
Note: There are five empirical factors that can be used to evaluate the quality of data and the analysis performed. The five factors are: driving states, risk, level of control, measurements, and validity. The five factors presented in this figure explain the similarities, differences, advantages, and disadvantages among the different research methods.

IMPACT: This research project is expected to demonstrate one or more methods of using data from various sources to better understand road-user behavior. The concept of combining and using behavioral data from multiple sources is relatively new, and this work will pave the way for others to follow. Results from this project will clearly show many benefits of combining data to better understand behavior issues. Integration of human behavior collected using different methods could lead to faster design and testing of safety countermeasures and new geometric designs, resulting in fewer crashes and potentially saved lives. The integration of different human behavior data also could provide safe and effective methods for studying and testing emerging connected-vehicle and automation technologies.

ONGOING RESEARCH: The second year of Romo's research will concentrate on demonstrating applicability of fusing data from sources, such as driving simulator experiments and naturalistic driving studies, to gain an in-depth understanding about certain behaviors.

RESOURCES: The following publication resulted from this RAP research and is outlined below.

Romo, A., Mejia, B., & Yang, C. Y. D. (2014). *Utilizing Various Data Sources for Surface Transportation Human Factors Research: Workshop Summary Report* (Publication No. FHWA-HRT-14-077). FHWA Turner–Fairbank Highway Research Center, McLean, VA. View the report at http://www.fhwa.dot.gov/advancedresearch/pubs/14077/index.cfm.

Romo, A., Yang, C. Y. D. (2015). The science and art of putting drivers under the microscope. *Public Roads*. Accepted for publication in the March–April 2015 issue. Federal Highway Administration, Washington, DC.

PROJECT: **Prediction of Pavement Temperature Profiles Using Surface Temperatures: An Analytical Approach With Model Validation Based on Long-Term Pavement Performance Data**

ASSOCIATE: Dong Wang

SCHOOL: University of Illinois at Urbana–Champaign

PERIOD: June 2011–May 2013

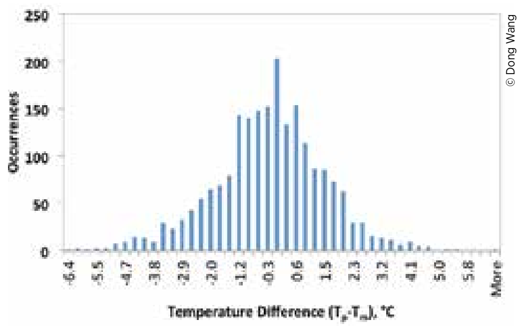
OBJECTIVE: To derive and field validate an easily implementable algorithm for predicting temperature profiles in paving materials.

ADVISER: **Yan "Jane" Jiang,** Office of Infrastructure Research and Development

SUMMARY: The mechanical properties of paving materials are usually temperature-dependent, but to accurately back-calculate the elastic moduli of pavement layers (i.e., the pavement's resistance to being deformed elastically when a force is applied to it), time-dependent pavement temperature must be known. Knowing the temperature profile allows researchers to better characterize the properties of paving materials and predict pavement responses under traffic and environmental loadings. Dong Wang's research project investigated a new method for predicting time-dependent pavement temperature profiles with limited inputs. There are currently three main methods for predicting temperature profiles: statistics-based models, numerical, and analytical approaches. These existing methods require large databases of climatic, meteorological, and geographical data and several other inputs to predict temperatures for the algorithms to operate effectively. Current pavement testing methods do not easily obtain the required climatic data; thus, these algorithms are subsequently limited in their ability to predict pavement temperature profiles. Wang focused his research effort on infrared pavement surface temperature data that can be easily obtained during pavement testing. This improved approach makes it possible to develop an entirely new algorithm for predicting a time-dependent pavement temperature profile that requires very limited inputs when compared with previous algorithms. The only inputs needed for this new method are infrared surface temperatures, initial pavement temperature profile, pavement geometry, and thermal properties of layer materials. Most important, unlike previous methods, no climatic data are required. To validate the new algorithm, when there are so many different types of pavement structures across regions with varied climatic conditions, an extremely large temperature dataset is required. To meet this requirement, Wang used data from the Long-Term Pavement Performance (LTPP) Program database for model validation.

IMPACT: Wang's research is expected to greatly benefit field engineers in characterizing pavement temperature for the purpose of analyzing and interpreting testing data. In addition, it could lead to high savings on pavement evaluation costs.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined in the following column.



Histogram of asphalt pavement subsurface temperature difference (predicted (T_p)-measured (T_m) temperature difference).

Wang, D. (2013). Prediction of asphalt pavement temperature profile during FWD testing: A simplified analytical solution with model validation based on LTPP data. *Journal of Transportation Engineering, 139*(1), 109–113.

Wang, D. (2012). Analytical approach to predict temperature profile in a multilayered pavement system based on measured surface temperature data. *Journal of Transportation Engineering, 138*(5), 674–679.

Wang, D. (2013). Simplified analytical approach to predict asphalt pavement temperature. *Journal of Materials in Civil Engineering* [accepted for publication].

Wang, D. (2013). Prediction of time-dependent temperature distribution within the pavement surface layer during FWD testing. *Journal of Transportation Engineering.* Manuscript submitted for publication.

Wang, D. (2012, July 5–7). *Prediction of time-dependent temperature profile in a slab.* Paper presented at the Third Advanced Workshop on Innovations and Modeling for Sustainable and Resilient Concrete Pavements, Quebec, Canada.

Wang, D. (2013, January 13–17). *Assessing BELLS3 equation in predicting asphalt layer temperature profile based on the latest LTPP FWD temperature data.* Paper presented at the 92nd Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2013, January 13–17). *Simplified analytical approach to predict temperature profile within a PCC slab during FWD testing.* Paper presented at the 92nd Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2012, January 22–26). *Model validation based on LTPP data to predict asphalt temperature profile.* Paper presented at the 91st Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2012, January 22–26). *Prediction of temperature profile in a multilayered pavement system using measured surface temperature data: An analytical approach.* Paper presented at the 91st Transportation Research Board Annual Meeting, Washington, DC.

PROJECT: **Tensile Response of Ultra-High Performance Concrete: Validation of Characterization Methods**

ASSOCIATE: **Luis Felipe Maya Duque**

SCHOOL: Polytechnic University of Madrid

PERIOD: June 2013–

OBJECTIVE: To critically assess the applicability of a recently proposed tensile test method for ultra-high-performance fiber-reinforced concrete.

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SUMMARY: Concrete is the most widely used construction material and has played a fundamental role in the development of infrastructure since the Romans. Advances in fiber-reinforced concretes over the last 50 years have enabled the development of an entirely new generation of cement-based composite materials. Ultra-High Performance Concretes (UHPC) represent a class of cement composites with high compressive strength and whose tensile response is characterized by high strain capacity accompanied by multiple microcracking. To take full advantage of the tensile behavior of these UHPC materials, it is necessary to develop tensile test methods and guidelines to be incorporated into codes and recommendations. Luis Felipe Maya Duque's research project focused on the assessment of proposed test methods designed to provide a reliable assessment of UHPC tensile behavior, not only in a research environment, but also for quality control purposes in a production environment. Maya Duque assessed a singular direct tensile test method that has already been the subject of FHWA research to establish advantages and drawbacks compared with existing methods. Maya Duque also conducted a critical review of the state of the art in tensile test methods for UHPC. The research project included an extensive experimental campaign to properly assess the performance of the proposed tensile test method. Furthermore, Maya Duque also considered the suitability of the direct tension test method to accurately reflect the influence of the fiber distribution and orientation in structural elements.

Casting of beam splice connection.

Full-scale flexural test of a beam splice connection made of Ultra-High Performance Concrete.

IMPACT: This research allows for the development and implementation of a quality control test method for UHPC in a production environment. Broader use of UHPC could lead to more durable and longer-lasting highway structures, reducing the cost and risks associated with reconstruction.

ONGOING RESEARCH: FHWA conducted over 120 direct tension tests on both mold-cast and sawed specimens to assess the influence of flow conditions as well as fiber orientation and fiber distribution on the tensile response of UHPC. FHWA also performed flexural tests on UHPC strips and slabs to correlate the results from the material characterization tests with the mechanical response of structural elements. Those results will contribute to assessing the reliability of the current design approaches as well as to improving understanding of the main mechanisms and variables to be considered in the development of design codes and recommendations. Maya Duque continues to complete the assessment of the structural efficiency of fiber reinforcement in UHPC structures through an experimental and analytical validation process at FHWA. FHWA plans to conduct two full-scale beam tests at the TFHRC Structures Laboratory. The results of these tests will provide insight for the development of continuity connection using UHPC as an alternative to increase the span range currently covered by conventional precast prestressed concrete girders.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Maya, L. F., Zanuy, C., Albajar, L., Lopez, C., & Portabella, J. (2013). Experimental assessment of connections for precast concrete frames using ultra high performance fibre reinforced concrete. *Construction and Building Materials, 48*(11), 173–186.

Maya, L. F, Fernandez Ruiz, M., Muttonni, A., & Foster, S. J. (2012). Punching shear strength of steel fibre reinforced concrete slabs. *Engineering Structures, 40,* 83–94.

Graybeal, B., & Baby, F. (2013). Development of a direct tension test method for ultra-high-performance fiber-reinforced concrete. *ACI Materials Journal, 110*(2) 177–186.

Graybeal, B. (2014). Splice length of prestressing strands in field-cast UHPC connections. *Materials and Structures*.

The following Web site provides insight on the FHWA UHPC research portfolio:

http://www.fhwa.dot.gov/research/resources/uhpc/

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EXPLORATORY ADVANCED RESEARCH

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