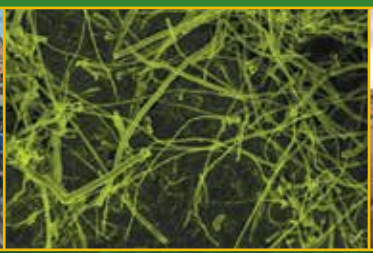
EXPLORATORY ADVANCED RESEARCH

EAR Program Research Results



U.S. Department of Transportation
Federal Highway Administration

EAR Program Research Results

Exploratory Advanced Research . . .
Next Generation Transportation Solutions

The Exploratory Advanced Research (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—where there is a community of experts from different disciplines who likely have the talent and interest in researching solutions and who likely would not do so without EAR Program funding.

Broad scientific participation and extensive coverage of advanced ideas and new technologies are secured by engaging stakeholders throughout the EAR Program's processes—not only in identifying and scoping topics, but also in ensuring the technical quality of sponsored research through expert panels and in communicating research results.

This catalog of results documents the output of that effort, a critical link in the chain of research, development, and deployment of new technology and practices necessary for the United States to have the best transportation system in the world for decades to come.

The EAR Program focuses investments in areas where changes in science and engineering can dramatically lead towards making the highway system safer, more durable, and more efficient:

- Breakthrough Concepts in Materials Science.
- Integrated Highway System Concepts.
- Human Behavior and Travel Choices.
- New Technology and Advanced Policies for Energy and Resource Conservation.

- Technology for Assessing Performance.
- Cross-cutting
  - Nanoscale Research.
  - Information Sciences.

The results of EAR Program–funded projects may include new fundamental insights and how they can be applied in highway transportation; new research methods, models, or data that can accelerate applied research; or new system concepts or prototypes, including laboratory testing and possibly limited field testing. The program does not fund projects through commercialization or deployment. Rather, results must be taken up by the research community, with the support of other funding sources. FHWA is committed to transitioning the results of EAR Program-funded projects and takes an active role in demonstrating results to audiences critical to continuing the research and development cycle.

Through six solicitations, the EAR Program has awarded 50 projects (37 of which are ongoing as of September 2012) involving both government and academic researchers. These projects represent the investment of $43 million in FHWA funds and leverage $17 million in matching funds. Additional projects will be funded in 2013. The following pages contain summary descriptions of the results of several recently completed research investigations.

Breakthrough Concepts in Material Science

PROJECT: **High-Performance Stress-Relaxing Cementitious Composites for Crack-Free Pavements and Transportation Structures**

INSTITUTIONS: Texas A&M University, Texas Transportation Institute

COMPLETED: July 2011

OBJECTIVE: To achieve a durable concrete with enhanced viscoelastic properties and high resistance to cracking through the utilization of nano inclusions.

CONTACT: **Richard Meininger,** 202-493-3191 (richard.meininger@dot.gov)

RESOURCES: Technical report at http://d2dtl5nnlpfr0r.cloudfront.net/swutc.tamu.edu/publications/technicalreports/476660-00017-1.pdf

Research article at http://www.hindawi.com/journals/jnm/2012/371927

RESULTS: Investigators performed a comprehensive review of previous work using carbon nanofilaments (CNFs) and tubes (CNTs) in cementitious materials to improve their mechanical properties and behaviors, and conducted a detailed study of the common method of incorporating CNFs. They developed a novel thermodynamic-based dispersion quantification method to measure the effect of geometry-dependent clustering on CNF dispersion in cement paste. They also developed a new method for improving and stabilizing CNF dispersion in cement paste using silica fume to significantly improve CNF dispersion in a hardened cementitious matrix. Finally, experimental investigation of the effect of CNFs on the mechanical behavior and properties of hardened cement paste showed that CNFs can increase flexural strength and reduce shrinkage cracking. The researchers produced an advanced hardened cement paste that is strong and resists shrinkage cracking quite well under certain levels of restraint. Next steps could include additional exploratory advanced research.

IMPACT: Use of new materials such as CNTs can lead to increased durability of pavements and structures as well as to multifunctional materials such as self-sensing pavements.

Human Behavior and Travel Choices

PROJECT: **Driver Behavior in Traffic**

INSTITUTIONS: Virginia Polytechnic Institute and State University in partnership with PTV America and the Virginia Center for Transportation Innovation and Research

COMPLETED: February 2012

OBJECTIVES: To characterize driver behavior using naturalistic driving data and agent-based modeling techniques for development of effective strategies to improve transportation safety and operations.

CONTACT: **David Yang,** 202-493-3284 (david.yang@dot.gov)

RESOURCES: Final report at http://www.ntis.gov. Search: PB2012-105330.

RESULTS: This research provides a foundation for agent-based modeling of driver behavior based on naturalistic data through an integrated framework for safety and operation analysis. Lateral vehicle action was simulated in a microscopic traffic behavior modeling environment, bringing new insights to the modeling of driver maneuvering behavior during safety-critical events. Agents developed and evaluated in the VISSIM simulation platform revealed a close resemblance to real driver data. The project team improved car-following models through development of a hybrid model for greater accuracy and flexibility and through the addition of the new "passing and hook-following" thresholds. They used the model to simulate vehicle actions in safety-critical events, developed agent-based simulation components integrated with the VISSIM simulation package through its driver model, and developed and implemented a robust activation mechanism for agent-based simulation based on discriminant analysis. The investigators also identified key future research issues: adaptability of agents in real time and human factors issues related to warning individual drivers about changes in their driving behavior that might lead to safety-critical events.

IMPACT: New behavioral models are necessary to predict the safe and efficient use of new connected vehicle and roadside technology. This project demonstrates the ability of agent-based models based on naturalistic driving studies to create new and improved behavioral models.

Human Behavior and Travel Choices

PROJECT: **Modeling the Urban Continuum in an Integrated Framework: Location Choice, Activity-Travel Behavior, and Dynamic Traffic Patterns**

INSTITUTIONS: Arizona State University with the University of Arizona and the University of Washington

COMPLETED: March 2012

OBJECTIVE: To develop a conceptual framework, integrated prototype, and computational tools for modeling interactions between the built environment and multimodal transportation systems and modeling urban systems across simulated land use, travel demand, and traffic flow.

CONTACT: **Brian Gardner,** 202-366-4061 (brian.gardner@dot.gov)

RESOURCE: Project Web site at http://urbanmodel.asu.edu/intmod.html

RESULTS: SimTRAVEL, developed in this project, is an integrated modeling system that advances land-use and transportation microsimulation by providing seamless modeling of longer term choices about location (home, work, school) and shorter term choices of activity, travel mode, and route. SimTRAVEL integrates the use of UrbanSim (a land-use model), OpenAMOS (an activity-based microsimulation model), PopGen (a state-of-the-art synthetic population generator), and DynusT/MALTA (a dynamic traffic assignment and microsimulation model) within a behaviorally robust framework. The integrated systems have been fully implemented in a user-friendly software environment with powerful graphical user interfaces and visualization dashboards. Open-source software architecture with multithreading and parallel-computing capabilities speeds simulations. SimTRAVEL was successfully tested and validated on a 500,000 population subregion of Maricopa County, AZ.

IMPACT: The innovations in this modeling software, which is freely available to the modeling community, are expected to have a major impact on transportation planning for sustainable futures.

Integrated Highway System Concepts

PROJECT: **Layered Object Recognition System for Pedestrian Collision Sensing**

INSTITUTIONS: Sarnoff Corporation with AutoLiv Electronics America

COMPLETED: December 2009

OBJECTIVE: To develop a real–time, in–vehicle, vision–only system to detect pedestrians and determine potential collisions with high accuracy and minimal false alarms.

CONTACT: **Wei Zhang,** 202–493–3317 (wei.zhang@dot.gov)

RESOURCES: Conference paper at http://onlinepubs.trb.org/onlinepubs/conferences/2011/RSS/2/Zhang,W.pdf

Final report at http://www.fhwa.dot.gov/publications/research/safety/11056/11056.pdf

RESULTS: The project team developed an in-vehicle, stereo vision–based system that detects, recognizes, and tracks pedestrians in its field of view. The system uses contextual information to reduce false alarms and light-enhancing techniques to improve low-visibility detection. Evaluated on publicly available datasets, the system matched or exceeded the performance of leading pedestrian detectors, tracking pedestrians at vehicle speeds of up to 48 km/h (30 mi/h) and distances up to 35 m (115 ft) away under good visibility conditions and up to 25 m (82 ft) away under reduced visibility with a 90-percent overall positive detection rate. The researchers recommend further development to upgrade performance. The feasibility of commercial implementation is high, since the system uses low-cost components.

Visual output of the pedestrian-detection system as it recognizes crossing pedestrians.

IMPACT: Twilight hours are the most dangerous time for pedestrians. Existing detection systems, however, have limited effectiveness in low-light conditions. New approaches introduced in this study provide superior results in twilight.

Integrated Highway System Concepts

PROJECT: **Development and Evaluation of Selected Mobility Applications for VII**

INSTITUTIONS: California PATH (Partners for Advanced Transit and Highways), University of California, Berkeley, and Caltrans

COMPLETED: July 2011

OBJECTIVE: Develop new strategies to reduce bottlenecks, minimize congestion, and maximize throughput by utilizing the capabilities of intelligent vehicles and highway infrastructure.

CONTACT: **Bob Ferlis,** 202-493-3268 (robert.ferlis@dot.gov)

RESOURCES: Final report at http://www.dot.ca.gov/newtech/researchreports/reports/2011/task_2138-tsm.pdf

Project Web site at http://gateway.path.berkeley.edu/~xylu/files/Truck_Control.html

RESULTS: The project team modeled, tested, and demonstrated prototype wireless communication systems to improve traffic flow by calculating and communicating variable speed limits (VSL) to drivers; achieve higher effective lane capacities using cooperative adaptive cruise control (CACC); and reduce fuel consumption and increase truck-only lane capacity with automated platoons.

Variable Speed Limits—In simulation and live tests on I-80, the researchers broadcast speeds calculated to prevent traffic flow breakdowns, with promising results. VSLs show significant potential to prevent traffic delays.

Cooperative Adaptive Cruise Control—Study results show that CACC could substantially increase highway capacity when it reaches moderate to high market penetration. Retrofitting non-CACC vehicles with inexpensive "here I am" radios could accelerate achievement of these capacity benefits.

Automated Truck Platoon Control—A wireless communications system successfully coordinated a platoon of three tractor-trailer trucks traveling at 85 km/h (53 mi/h) and in varied joining and splitting maneuvers. Fuel savings were estimated at 10 to 14 percent for the following trucks.

IMPACT: New connected vehicle and highway systems can lead to substantial safety, operational, and environmental benefits.

Technology for Assessing Performance

PROJECT: **Flexible Skin Areal Shear Stress and Pressure Sensing System for Experimental Bridge Scour Research**

INSTITUTIONS: National Aeronautics and Space Administration Jet Propulsion Lab and FHWA Hydraulics Research Laboratory

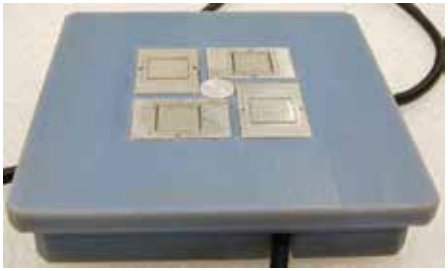
COMPLETED: May 2011

OBJECTIVE: To advance technology for measuring and understanding the complex flow fields and boundary shear stresses and pressure fields associated with bridge pier scour.

CONTACT: **Kornel Kerenyi,** 202-493-3142 (kornel.kerenyi@dot.gov)

RESOURCE: Technical report at http://trs-new.jpl.nasa.gov/dspace/bitstream/2014/41997/1/11-0813.pdf

RESULTS: In this project, the Jet Propulsion Laboratory conducted research on an integrated, flexible-skin, areal shear- and pressure-sensor system in a miniaturized array that measures changes in shear stress and pressure associated with scour-hole formation. The sensor elements were intended to measure shear forces in the range of 0.05 to 6 Pa and variations in pressure in the range of 0 to ±100 Pa, with a sampling rate of more than 500 data points per second. Such a system will help researchers understand erosive flow mechanisms related to turbulence structures, together with local flow convergence and contractions around the fronts and flanks of piers or between piles of complex pier configurations. Direct measurements of shear forces are essential to validated computational fluid dynamic models.



The flexible (skin) sensing system is based on an elastically mounted, floating plate concept. A single pressure sensor was inserted in the middle of this array. The optical encoder of each shear force sensor is encapsulated so the assembled sensor can be immersed in water.

IMPACT: Scour is the predominate cause of failure in bridges over water. The ability to capture shear stress and pressure data will significantly aid small-scale scour experiments in bridge scour research.

Technology for Assessing Performance

PROJECT: **Development of Stiffness Measuring Device for Pad Foot Roller Compaction**

INSTITUTIONS: Colorado School of Mines, with Caterpillar Inc., BOMAG, and the Colorado Department of Transportation

COMPLETED: June 2011

OBJECTIVES: To develop a methodology to achieve continuous, real-time sensing of soil properties during static compaction with a pad foot roller.

CONTACT: **Mike Adams,** 202-493-3025 (mike.adams@dot.gov)

RESOURCES: Poster presentation at http://smartgeo.mines.edu/upload/poster_soil.pdf

Conference paper at http://control.mines.edu/mooney/docs/RealTimeSoilCompactionMonitoringPadStrain.pdf

RESULTS: Measurement of soil stiffness during compaction of foundations for highway structures is critical to ensuring that design-life specifications are met. In this study, investigators developed a conceptual framework for determining pad–soil contact force and displacement (and thus soil stiffness) from sensors built into the pads and roller, constructed a prototype measurement system, and devised a wireless data acquisition system to enable field-scale testing. They successfully measured plastic and elastic soil deformation during compaction using laser-based distance sensors and pad-strain-based techniques. Laboratory and field testing confirmed the predicted strain field changes. Some elements of the model need further refinement to ensure repeatable and accurate measurement across various soil conditions.

Strain gages, installed within selected pads that are welded to the drum, are wired to a signal processing box that transmits data wirelessly to a computer in the cab.

IMPACT: Intelligent compaction allows 100 percent quality control in real time. More comprehensive, accelerated measurement of compaction could improve long-term performance of roadway base courses and extend pavement life.

GETTING INVOLVED WITH THE EAR PROGRAM

To take advantage of a broad variety of scientific and engineering discoveries, the EAR Program involves both traditional stakeholders (State department of transportation researchers, University Transportation Center researchers, and Transportation Research Board committee and panel members) and nontraditional stakeholders (investigators from private industry, related disciplines in academia, and research programs in other countries) throughout the research process.

LEARN MORE

For more information, see the EAR Program Web site at www.fhwa.dot.gov/advancedresearch. The site features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

For additional information, contact:
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Zachary Ellis, 202-493-3193 (email: zachary.ellis@dot.gov)

Cover photos: *Left*, illustration of the layer-based pedestrian recognition method, courtesy of SRI International. (Actual display output from an onboard system is shown on page 7.) *Center*, carbon nanofibers, used to enhance concrete structural properties (image width about 15 micrometers) (courtesy of Texas A&M University). *Right*, pad foot roller compactor outfitted for real-time measurement of soil properties (©Colorado School of Mines).

EAR PROGRAM RESULTS

The EAR Program strives to develop partnerships with the public and private sectors because the very nature of EAR is to apply ideas across traditional fields of research and stimulate new approaches to problem solving. The program bridges basic research (e.g., academic work funded by National Science Foundation grants) and applied research (e.g., studies funded by State departments of transportation). In addition to sponsoring EAR projects that advance the development of highway infrastructure and operations, the EAR Program is committed to promoting cross-fertilization with other technical fields, furthering promising lines of research through dissemination and continued investigations, and deepening vital research capacity.

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