EXPLORATORY ADVANCED RESEARCH

EAR Program Research Results

Updated through 2013

U.S. Department of Transportation
Federal Highway Administration

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Cover photos

Left: Computing and navigating instruments in the trunk of a project test vehicle, demonstrated at FHWA's Turner-Fairbank Highway Research Center (see pages 7, 8, and 9 and the report of an EAR Program–sponsored workshop on vehicle positioning at http://www.fhwa.dot.gov/advancedresearch/pubs/13052/13052.pdf).

Right: FHWA's Highway Driving Simulator, located at the Turner-Fairbank Highway Research Center, used in a project's comparison of results from four simulator platforms (see page 15).

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:

- Connected Highway and Vehicle System Concepts.
- Breakthrough Concepts in Materials Science.
- 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 seven solicitations, the EAR Program has awarded 59 projects (36 of which are ongoing as of September 2013) involving both government and academic researchers. These projects represent the investment of $50 million in FHWA funds and leverage $19 million in matching funds. Additional projects will be funded in 2014. The following pages contain summary descriptions of the results of selected recently completed research investigations.

Contents

PROJECT: **Intersection Control for Autonomous Vehicles**

INSTITUTION: University of Texas at Austin

COMPLETED: 2013

OBJECTIVE: To develop, test, and evaluate (in simulation with a full-size robotic vehicle) traffic control algorithms for autonomous intersection management (AIM) and autonomous vehicles.

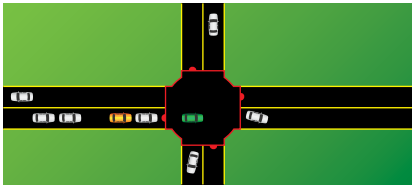
CONTACT: **Gene M. McHale,** FHWA Office of Operations R&D

RESOURCES: Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-07-0026

Research reports and simulation videos at http://www.cs.utexas.edu/~aim/

RESULTS: The project demonstrated that AIM, in conjunction with autonomous vehicles communicating with each other and with roadside equipment, can dramatically improve intersection efficiency, reduce traffic delays, and alleviate traffic congestion. The research team developed and tested traffic control algorithms for autonomous vehicles and evaluated them first in simulation only and then in simulation integrated with a full-size robotic vehicle. Among several important project innovations are the following:

- Parameters for an autonomous vehicle to safely cross an intersection in an AIM system.
- A setpoint-scheduling algorithm to control arrival time, velocity, and position of an autonomous vehicle by sending control parameters to its brake and throttle actuators.
- Prioritization schemes to allocate intersection access and keep traffic moving.
- A preemptive, fail-safe protocol to prevent collisions when mechanical failures occur.



An AIM simulation, which shows virtual and real vehicles at an intersection. White vehicles have a reservation to enter the intersection; yellow vehicles do not. The green vehicle is a proxy, representing the real-world location of the autonomous vehicle.

IMPACT: As automated vehicles come onto the market, results from this project have the potential to provide a safe system for improving traffic flow and dramatically reducing fuel use and mobile source emissions at intersections.

PROJECT: **Advanced Freeway Merge Assistance: Harnessing the Potential of Connected Vehicles**

INSTITUTION: University of Virginia Center for Transportation Studies

COMPLETED: 2012

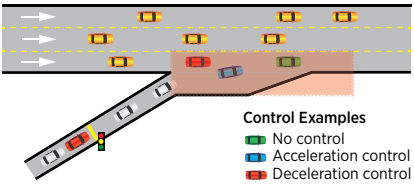
OBJECTIVE: To develop and evaluate candidate freeway merge assistance systems that might improve the efficiency and safety of freeway merges in a connected vehicle environment.

CONTACT: **Robert A. Ferlis,** FHWA Office of Operations R&D

RESOURCE: Project details and final report at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=fhwa-proj-09-0066

RESULTS: The project team developed four algorithms that use connected-vehicle data to improve freeway merging strategies: lane-level variable speed limit, lane-changing advisory, gap-responsive on-ramp signal, and merging control. The team evaluated the algorithms within a connected vehicle simulation environment that simulates both vehicle movement and communications. The lane-level variable speed limit approach, lane-changing advisory, and gap-responsive on-ramp signal algorithms did not produce statistically significant improvement, although they showed potential. The merge-control algorithm, however, generated statistically significant benefits in average speed (23.6 percent increase), travel time (11.5 percent decrease), delays (17.9 percent decrease), and miles traveled (2.4 percent increase) within the connected vehicle environment. A sensitivity analysis of market penetration rates revealed that significant system improvements occur when 50 percent or more vehicles have connective capabilities.

IMPACT: These results will help transportation agencies understand the value of connected vehicle technology as it emerges and may eventually lead to freeway merge areas with greater capacity and fewer crashes.



Freeway merge control example. Within the merging area, the acceleration of the vehicles is controlled: leading (green, no change), entering (blue, acceleration), and following (red, deceleration).

PROJECT: **Next Generation Vehicle Positioning in GPS-Degraded Environments for Vehicle Safety and Automation Systems**

INSTITUTIONS: Auburn University, Kapsch TrafficCom, Pennsylvania State University, Stanford Research Institute

COMPLETED: 2012

OBJECTIVE: To provide ubiquitous, precise positioning in regard to vehicle safety and automation in the presence of Global Positioning System (GPS) degradation.

CONTACT: **David Gibson,** FHWA Office of Operations R&D

RESOURCES: Final report, presentations, and video at http://www.eng.auburn.edu/~dmbevly/FHWA_AU_EAR2/

Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-09-0061

Camera and LIDAR equipment mounted on the roof of the test vehicle.

RESULTS: The project team developed an integrated vehicle positioning system in which subsystems with complementary strengths are fused to provide precise positioning data in environments where one or more of the subsystems could fail. The subsystems assessed were GPS, inertial navigation systems (INS), camera and LIDAR lane departure warning systems, a dedicated short-range communications distance estimation system, visual odometry, and a road fingerprinting system. The accuracy and robustness of integrated systems were evaluated in test track and roadway scenarios under various weather conditions and at various speeds. The subsystems helped to improve lane-level accuracy. In live tests, GPS/INS integration provided improved results over standalone GPS, particularly in heavy foliage and urban canyon environments, and the full system of sensors performed best overall.

IMPACT: New algorithms, data fusion techniques, and ways of handling GPS data discovered in the project can support major improvements in vehicle positioning performance. Data fusion techniques can produce low-cost, precise positioning, allowing for a range of safety and mobility applications that currently would require high-cost equipment.

PROJECT: **Innovative Approaches for Next Generation Vehicle Positioning**

INSTITUTION: University of California, Riverside

COMPLETED: 2012

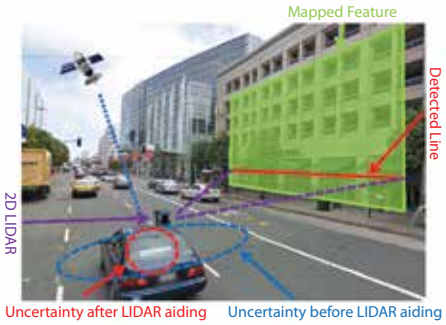
OBJECTIVE: To investigate and test a range of approaches that could provide lane-level positioning accuracy in diverse driving environments.

CONTACT: **James A. Arnold,** FHWA Office of Operations R&D

RESOURCE: Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-09-0062

RESULTS: No single positioning technology can meet the requirements for lane-level positioning across diverse driving environments—each has performance limitations. This project explored the most promising technologies for improving the accuracy, availability, and reliability of vehicle positioning by augmenting Global Navigation Satellite System/Inertial Navigation System technology. After evaluating the performance of aiding technologies (LIDAR, radar, computer vision, and dedicated short-range communication (DSRC)), the research team developed and tested prototype systems that integrate a variety of sensors. The team found that LIDAR and radar technology integrate with the quickest processing and response, and terrestrial radio navigation and DSRC methods require more time. Radio and DSRC-based methods show great promise because implementation costs are relatively low, but require further development to improve accuracy. The performance of vision-based aiding improves with increased sensor cost; however, implementation requires development of onboard feature mapping.

IMPACT: This project's theoretical and experimentally demonstrated results will facilitate continued rapid advancement in vehicle positioning technology, providing opportunities for new safety, mobility, and eco-drive applications.



Typical use of two-dimensional LIDAR to aid positioning in urban areas.

PROJECT: **Development of Enhanced Safety Systems Based on GPS/INU System**

INSTITUTIONS: Ohio State University, University of Virginia, DGNSS Solutions, LLC

COMPLETED: 2012

OBJECTIVE: To test emerging navigation technologies in a simulation environment that could lead to better assessment of future navigation technology and improved methods for roadway design.

CONTACT: **James A. Arnold,** FHWA Office of Operations R&D

RESOURCE: "Integrated GNSS/INU, Vehicle Dynamics, and Microscopic Traffic Flow Simulator for Automotive Safety," *Proceedings, 14th International IEEE Conference on Intelligent Transportation Systems,* 2011, at http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6082995

RESULTS: The project team developed an integrated simulation platform to evaluate the impact of emerging vehicle positioning and communications technologies that provide level positioning at less than 10 cm (3.9 inch) and allow connected vehicles and infrastructure to monitor and share safety-related information. To estimate how system errors, communication delays, and communication interruptions affect the timing of warnings, driver perceptions/reactions, network-wide delays, and safety, the team simulated warning scenarios for eight sensor system combinations. The team found that error- and delay-free driver warnings reduce the number of conflicts in the range of 28 percent to 50 percent. The project compared different positioning approaches for overall accuracy and for providing the fewest false and missing warnings.

IMPACT: Use of the integrated simulation environment to assess connected vehicle technologies and improve roadway design can reduce the risk of crashes, prevent travel delays, and reduce fuel consumption as new systems are implemented.

PROJECT: **Advanced Traffic Signal Control Algorithms**

INSTITUTIONS: California Department of Transportation; California PATH, University of California, Berkeley; Center for Environmental Research and Technology, University of California, Riverside; BMW Group

COMPLETED: 2013

OBJECTIVE: To develop advanced signal control strategies based on connected vehicle data, that is, real-time information on a vehicle's location, speed, and characteristics, as well as communication to the signal control infrastructure.

CONTACT: **Peter Huang,** FHWA Operations R&D

RESOURCES: Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-10-0009

Technical report at http://www.ocf.berkeley.edu/~xuanyg/Argote_Christofa_Xuan_Skabardonis_2012_TRB.pdf

RESULTS: The research team developed and tested several signal control applications, including strategies to minimize the occurrence of red-light running. The team's prediction algorithm for DARE (dynamic all-red extension when a high probability of collision exists) achieved a correct detection and activation rate over 95 percent. Strategies to reduce arrival flow during the yellow interval, which influences red-light running in coordinated arterials, were also effective. To minimize fuel consumption, the team developed an in-vehicle speed advisory system that achieved fuel savings of over 13 percent in field tests. The team also proposed new methods for estimating common arterial measures of effectiveness for different penetration rates of connected vehicles. In one example, the team found that to accurately estimate intersection queue length in lighter traffic conditions, 80 percent of vehicles need to have connectivity, but in oversaturated conditions, only 10 percent need to be equipped. This finding indicates that connective traffic control strategies may be possible in the most congested networks before connected vehicles are ubiquitous.

IMPACT: The project results show great potential to advance real-time signal control strategies in some cases with low levels of new technology adoption. Improved efficiency will reduce travel time, frequency and length of stops, fuel consumption, and harmful emissions.

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

INSTITUTIONS: Sarnoff Corporation, AutoLiv Electronics America

COMPLETED: 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,** FHWA Office of Safety R&D

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.

Connected Highway and Vehicle System Concepts

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

INSTITUTIONS: California PATH, University of California, Berkeley; California Department of Transportation

COMPLETED: 2011

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

CONTACT: **Robert A. Ferlis,** FHWA Office of Operations R&D

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.

PROJECT: **Greatly Increased Use of Fly Ash in Hydraulic Cement Concrete for Pavement Layers and Transportation Structures**

INSTITUTIONS: Purdue University, Auburn University, National Institute of Standards and Technology, National Ready Mixed Concrete Association, FHWA's Chemistry and Concrete Laboratories

COMPLETED: 2012

OBJECTIVE: To improve understanding of infrastructure materials, specifically, how to use higher amounts of fly ash in concrete and obtain the performance needed for long-lasting concrete highway pavements and structures.

CONTACT: **Richard C. Meininger,** FHWA Office of Infrastructure R&D

RESOURCES: Final report at http://www.nrmca.org/research_engineering/Documents/Lab_fly_ashFinal_report.pdf

Presentation at http://webpages.mcgill.ca/staff/Group3/aboyd1/web/Conferences/AMW%20XI/Presentations/Meininger%20Rev.pdf

Fly ash with different carbon content levels.

RESULTS: Large-scale experiments demonstrated that high-volume fly ash (HVFA) concrete can be produced to have setting times and early-age compressive strength development comparable to conventional portland cement concrete. In experiments with HVFA replacement volumes of 40 percent and 60 percent, researchers found that lower water-to-cementitious materials ratios and internal curing (adding pre-wetted lightweight aggregates that release water to the matrix after time of set) improved early-age strength and reduced early-age cracking. Other project studies examined materials compatibility, prediction methods for property development, improved freezing and scaling durability, and activation energy values of cementitious materials. Technology transfer activities in the project will guide agencies and contractors in using HVFA in concrete mixtures.

IMPACT: The performance data and best practices flowing from this project can lead to significantly increased use of fly ash in concrete mixtures, resulting in transportation infrastructure with a smaller carbon footprint, lower embodied energy, and improved long-time performance.

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

INSTITUTIONS: Texas A&M University, Texas Transportation Institute

COMPLETED: 2011

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

CONTACT: **Richard C. Meininger,** FHWA Office of Infrastructure R&D

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.

PROJECT: **Making Driving Simulators More Useful for Behavioral Research**

INSTITUTIONS: University of Iowa/National Advanced Driving Simulator; University of Wisconsin; Western Transport Institute, Montana State University; Battelle; Entropy Control, Inc.; William H. Levison Associates

COMPLETED: 2013

OBJECTIVE: To develop a mathematical transformation that will allow scientists and engineers to better predict the behavior of drivers in real environments based on the results of experiments conducted in driving simulators.

CONTACT: **Brian Philips,** FHWA Office of Safety R&D

RESOURCE: Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-09-0067

RESULTS: The research team identified highway design needs and matched them to specific characteristics of driving simulators (e.g., motion, field of view, speed, and steering torque) and developed and demonstrated tools to characterize how closely responses to simulator characteristics match real-world driving outcomes. In experiments conducted on four different simulator platforms, the researchers compared driver judgment of simulator fidelity and performance in virtual roadway scenarios and found little effect of motion and a moderate effect of visual complexity. The results show that using a high-fidelity simulator, with attention to accurately rendering the visual complexity of the roadway, will lead drivers in the simulator to drive at speeds quite comparable to those observed on actual roadways.

Actual road data (red points) used in response comparisons for a roundabout scenario.

IMPACT: Models developed in this project will enable the driving safety research community and highway designers to predict real-world driving behavior more accurately from behavior in driving simulators and to integrate the results from different simulators more readily. The models also will better indicate to researchers when experiments require high fidelity simulation and when lower fidelity approaches are adequate, thereby saving time and funding on future studies.

PROJECT: **Behavioral Sciences Approach to Testing, Validating, and Establishing Best Practices for Alternative Highway Revenue Collection**

INSTITUTIONS: University of Central Florida and Georgia State University

COMPLETED: 2013

OBJECTIVE: To understand drivers' behavioral choices between tolled and "free" routes and choices of departure time by estimating risk attitudes, accuracy of risk perception, and discount rate.

CONTACT: **Karen White,** FHWA Office of Transportation Policy Studies

RESOURCES: Study summary at http://www.fhwa.dot.gov/advancedresearch/pubs/congestion/index.cfm

Presentation at http://www.transportationeconomics.org/meetings—open the link "An Experimental Economics Investigation into Responses to Congestion Pricing, Harb.

RESULTS: To improve understanding of when and why drivers choose a tolled facility, the research team used experimental economics with a population of local drivers and students participating in (1) stylized lotteries to reveal risk attitudes; (2) driving simulators to reveal risk attitudes and travel time perceptions; and (3) GPS-recorded actual driving choices. More than 550 drivers with residence and workplace connected by both a toll and a "free" route participated in Orlando, Florida, and Atlanta, Georgia. They responded to varying road prices in actual driving and simulations to assess their risk attitudes and travel time biases in response to monetary incentives. In another experiment, 210 college students participated in driving simulations of route choices to test whether their behavior could predict field driver behavior. The study concludes that risk attitudes are comparable across tasks and regions, and in college students versus field drivers. The researchers found evidence of risk aversion as captured both by sensitivity over values of route choices and by pessimism over likelihoods of congestion.

IMPACT: Currently revenue projections for priced roadways are based on methods with limited accuracy, which can result in projects with lower than expected revenue. The results of this research confirm the importance of accurately incorporating risk attitudes in policy analysis and impact assessment of congestion pricing. The use of less-costly subject pools and instruments to gather behavioral data as demonstrated in the project can increase opportunities to investigate driver choices and incorporate more accurate data when determining potential revenue.

PROJECT: **Effects of Automated Transit and Pedestrian/Bicycling Facilities on Urban Travel Patterns**

INSTITUTIONS: University of Michigan, University of Illinois at Chicago

COMPLETED: 2013

OBJECTIVE: To evaluate whether innovative pedestrian, bicycle, and transit facilities and services will attract travelers and decrease passenger car travel.

CONTACT: **Robert A. Ferlis,** FHWA Office of Operations R&D

RESOURCE: Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=FHWA-PROJ-09-0037

RESULTS: Researchers in this project found that high-frequency shuttle service between a neighborhood and a regional rail transit system with available capacity can have a significant effect on choice of travel mode. The researchers conducted a household survey in four metropolitan Chicago communities to assess whether community shuttle service, bike lanes, walkway improvements, and other amenities would increase use of rail transit. In each neighborhood, they queried 150 residents who lived within 1.5 mi (2.4 km) of a rail transit station and worked within 3 mi (4.8 km) of a station on their current travel patterns and mode preferences under the hypothetical improvements. Simulations using a combination agent-based/activity-based model predicted that neighborhood shuttle service combined with bike lanes would decrease car use from 36 percent to 22 percent and increase rail transit use from 50 percent to 67 percent. Predicted shifts to rail were higher in lower density communities with lower rail use.

IMPACT: The project's results support the value of continued research into automating high-frequency shuttle services to help reduce traffic congestion, fuel consumption, and greenhouse gas emissions.

PROJECT: **Megaregional Travel**

INSTITUTIONS: University of Maryland, National Center for Smart Growth; ECONorthwest; Parsons Brinckerhoff; LEAM Group, University of Illinois at Urbana/Champaign; and David Simmonds Consultancy

COMPLETED: 2013

OBJECTIVE: To develop methods and tools that support planning for the Nation's megaregions, integrating multiple disciplines, travel modes, and geographic levels.

CONTACT: **Supin Yoder,** FHWA Office of Planning

RESOURCES: Report at http://www.pbworld.com/pdfs/pb_in_the_news/moeckel_weidner_et_al_trb2012_mega-region_framework_analyzing_high_energy_price_future.pdf

Case study at http://www.fhwa.dot.gov/planning/megaregions/reports/

RESULTS: Megaregions, large agglomerations of metropolitan areas, represent a development pattern spreading across the world and a new planning geography. In this project, researchers developed and demonstrated the Megaregion Market Analysis Framework, which contains a market analysis and analytic tools. The market analysis focuses on defining the megaregion's boundaries, identifying issues it must address, and describing its characteristics. The analytic tools—an economic model linked with a travel demand model—enable analysis of the intricate effects of economic changes on a megaregion's economy and transportation system. Applying this framework, the project defined the Chesapeake megaregion and used existing models and data to identify its issues and characteristics. The market analysis illustrates the need to broaden the planning perspective beyond local and metropolitan areas.

IMPACT: This project provides the framework and tools for policy makers to understand issues such as freight and the economy on a megaregional scale and demonstrates that analytic tools can be developed with available data and at reasonable cost for megaregional analysis.

PROJECT: **Driver Behavior in Traffic**

INSTITUTIONS: Virginia Polytechnic Institute and State University, PTV America, Virginia Center for Transportation Innovation and Research

COMPLETED: 2012

OBJECTIVE: 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,** FHWA Office of Safety R&D

RESOURCE: 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.

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

INSTITUTIONS: Arizona State University, University of Arizona, University of Washington

COMPLETED: 2012

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

CONTACT: **Brian Gardner,** FHWA Office of Planning, Environment, & Realty

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 the simulations. SimTRAVEL was successfully tested and validated on a 500,000 population subregion of Maricopa County, Arizona.

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.

PROJECT: **Nanoscale Sensors for Structural Health**

INSTITUTION: Georgia Institute of Technology

COMPLETED: 2013

OBJECTIVE: To develop and field-test the use of wireless, self-powered nanosensors and nanosensor arrays for real-time, autonomous strain and crack monitoring of steel bridges and other structures.

CONTACT: **Shane Boone,** FHWA Office of Infrastructure R&D

RESOURCES: "Passive Wireless Antenna Sensor for Strain and Crack Sensing—Electromagnetic Modeling, Simulation, and Testing," *Smart Materials and Structures*, vol. 22, p. 085009, 2013, at http://iopscience.iop.org/0964-1726/22/8/085009/.

"Passive Wireless Smart-Skin Sensor Using RFID-based Folded Patch Antennas," *International Journal of Smart and Nano Materials*, vol. 2, pp. 22–38, 2011, at http://www.tandfonline.com/doi/full/10.1080/19475411.2010.545450#preview.

Project details at http://www.fhwa.dot.gov/research/tfhrc/projects/projectsdb/projectdetails.cfm?projectid=fhwa-proj-10-0014

Antenna sensor tracking crack propagation.

RESULTS: The research team has developed several types of wireless, self-powered, low-cost antenna sensors that can monitor potentially dangerous cracks in steel bridges. To reduce the costs of large-quantity production, multiple sensors are printed with inkjet printers and nanoscale conductive inks onto a thin, flexible film that can be applied to fatigue-prone areas of a bridge. The sensors create a network that can detect and measure multiple small cracks in proximity and their propagation. Powered by solar cells or energy captured from the signals of a wireless reader, the antenna sensor systems have great potential for low-cost, large-scale monitoring of transportation structures.

IMPACT: The research results demonstrate the potential for designing low-cost, advanced strain-sensing systems that can improve the efficiency of maintenance and repair for steel bridges, provide substantial savings in operations, and increase safety.

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's J. Sterling Jones Hydraulics Research Laboratory

COMPLETED: 2011

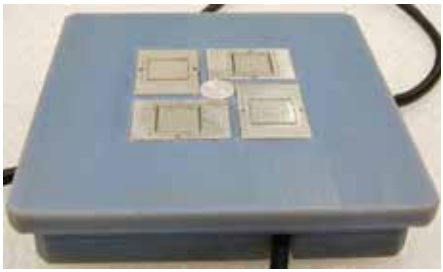
OBJECTIVE: To advance technology for measuring and understanding the complex flow fields and boundary shear stresses and pressure fields associated with bridge pier scour.

CONTACT: **Kornel Kerenyi,** FHWA Office of Infrastructure R&D

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.

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.



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.

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: 2011

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

CONTACT: **Mike Adams,** FHWA Office of Infrastructure R&D

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.

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.

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.

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.

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EXPLORATORY ADVANCED **RESEARCH**

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