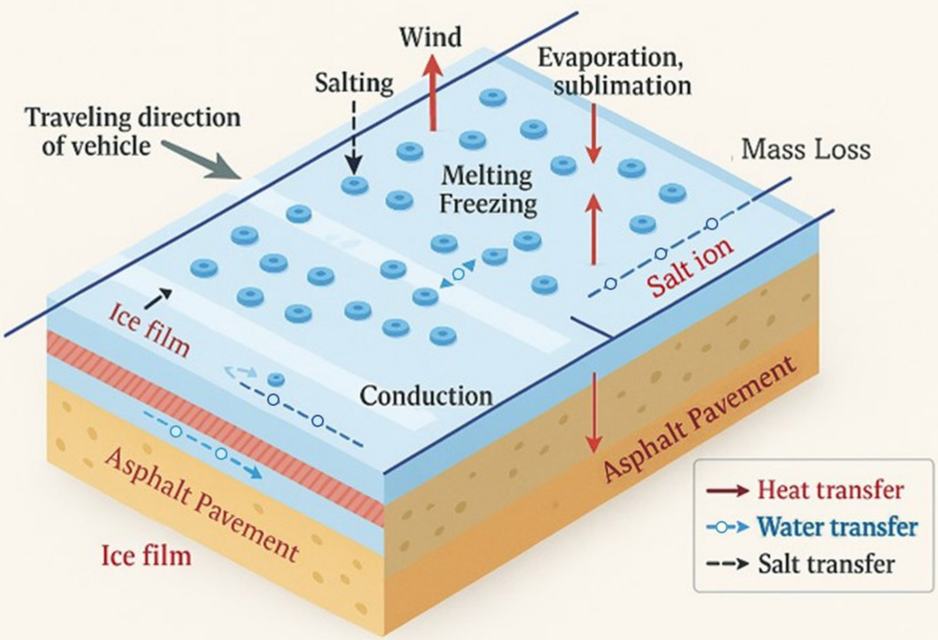
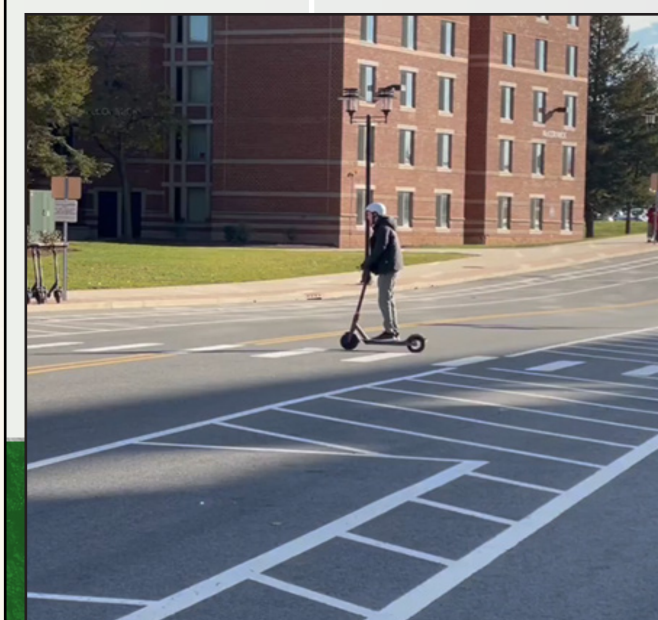
Exploratory Advanced Research (EAR) Program

Compendium of Papers From Funded Research Projects

2025

EXPLORATORY ADVANCED RESEARCH





U.S. Department of Transportation
Federal Highway Administration

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CONTENTS

DIGITAL TWINS

DIGITAL TWIN-ENABLED EXTENDED ACTIVE SAFETY ANALYSIS FOR MIXED TRAFFIC

Texas A&M Transportation Institute

Traffic safety is a primary focus for policymakers and transportation researchers. At the Texas A&M Transportation Institute, researchers are developing a novel framework for traffic safety analysis.[1] The study seeks to build a predictive, extended active safety approach for mixed traffic of human-driven vehicles and connected and automated vehicles through a digital twin technique, which creates a virtual replica of a physical object, system, or process, helping researchers understand real-world performance.

Submitted for Publication and Presentation

1. Anis, M., Y. Zhou, and D. Lord. 2025. “Learning From Geometry-Aware Near-Misses to Real-Time COR: A Spatiotemporal Grouped Random GEV Framework.” *arXiv*. https://arxiv.org/pdf/2509.02871, last accessed November 18, 2025. Under review by *Accident Prevention and Analysis*.

2. Wu, K., Z. Li, S. Li, X. Ye, D. Lord, and Y. Zhou. 2025. “AI^2-Active Safety: AI-Enabled Interaction-Aware Active Safety Analysis With Vehicle Dynamics.” *arXiv*. https://www.arxiv.org/pdf/2505.00322, last accessed November 18, 2025.

3. Wu, K, Z. Li, S. Li, X. Ye, D. Lord, and Y. Zhou. 2025. “AI^2-Active Safety: AI-Enabled Interaction-Aware Active Safety Analysis With Vehicle Dynamics.” Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

4. Zhang, H., Z. Li, K. Wu, D. Lord, Z. Tu, and Y. Zhou. 2025. “On the Collision Risk of Stochastic Traffic: Analytical Approximation in 2D and 3D Spaces for Generic Vehicles.” Under review by *Transportation Research Part B, Methodological*.

5. Zhang, H., X. Yue, K. Tian, S. Li, K. Wu, Z. Li, D. Lord, and Y. Zhou. 2025. “Virtual Roads, Smarter Safety: A Digital Twin Framework for Mixed Autonomous Traffic Safety Analysis.” *arXiv*. https://arxiv.org/pdf/2504.17968, last accessed November 18, 2025.

6. Zhang, H., X. Yue, K. Tian, S. Li, K. Wu, Z. Li, D. Lord, and Y. Zhou. 2025. “Virtual Roads, Smarter Safety: A Digital Twin Framework for Mixed Autonomous Traffic Safety Analysis.” *IEEE Internet of Things* 13, no. 4: 6045–6058. https://www.semanticscholar.org/paper/Virtual-Roads%2C-Smarter-Safety%3A-A-Digital-Twin-for-Zhang-Yue/d5c4a2e77625e290991cba84415486502ded9797, last accessed February 6, 2026.

7. Zhang, H., X. Yue, K. Tian, S. Li, K. Wu, Z. Li, D. Lord, and Y. Zhou. 2025. “Virtual Roads, Smarter Safety: A Digital Twin Framework for Mixed Autonomous Traffic Safety Analysis.” Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

SUPPLEMENTARY MATERIALS

EVALUATING AND IMPLEMENTING CC-I-L CEMENT FOR THE NEXT GENERATION OF CONCRETE BRIDGE CONSTRUCTION

Iowa State University, University of Florida, University of Texas at Austin, Georgia Institute of Technology, and Carnegie Mellon University

Calcined clay (CC)-based cement has emerged as a promising low-carbon alternative to ordinary portland cement (OPC) because it displays excellent resistance to chloride penetration, mitigation of alkali-silica reaction with reactive aggregates, and sulfate resistance.[2,3,4] Research has also shown that the heat released during the first 72 h of CC-based cement hydration is generally lower than that of OPC, which would be beneficial for concrete bridge foundations.[5] CC is widely available and cost effective. The research team in this study is developing viable low-carbon CC-based cementitious material options for pavement and bridges called CC-I-L, where the I stands for Type I cement and the L for limestone.[6] The project’s goals are to provide options for implementing low-carbon cement, identify gaps and develop strategies to overcome barriers to implementing CC-I-L cement, and develop a roadmap for national and State implementation of CC-I-L in pavement and bridge construction.

Presented

1. Gupta, S. 2025. "How Do Calcined Clays Impact Concrete Heat Rise?" Presented at the *2025 Natural Pozzolan Symposium*. Ogden, UT: Natural Pozzolan Association.

2. Huynh, P. 2025. "LC^3-Like Systems Made With Calcined Clays and U.S. Portland Limestone Cement." Poster presented at the *Center for Transportation Research 2025 Annual Symposium*. Austin, TX: Center for Transportation Research.

3. Huynh, P. 2025. "LC^3-Like Systems Made With Calcined Clays and U.S. Portland Limestone Cement." Poster presented at the *15th Advances in Cement-Based Materials*. Boulder, CO: American Ceramic Society.

4. Juenger, M. 2025. "Reducing Clinker Content Using Blended Type 1L Cements and Calcined Clays." Presented at the *ACI Foundation 2025 Concrete Innovation Forum*. Denver, CO: ACI Foundation.

5. Luo, D. 2025. "Properties of Calcined Clay-Limestone Cement Concrete." Presented at the *Carbon Conscious Concrete Symposium (C3 2025)*. Chicago, IL: C3 Symposium.

6. Luo, D., D. Wang, K. Wang, P. Taylor, L. Wathne, and D. Sanders. 2025. "Performance and Limitations of LC^3 Concrete Under Lab and Field Conditions." Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

7. Riding, K. 2025. "Thermal Performance of Calcined Clay Supplementary Cementitious Materials in Mass Concrete Applications." Presented at the *18th International Clay Conference*. Dublin, Ireland: Association Internationale pour l'Etude des Argiles.

8. Taylor, P. 2025. "Performance and Limitations of LC^3 Concrete Under Lab and Field Conditions." Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

9. Tran, T. 2025. "Effects of Blending Water-Reducing Admixtures (WRAs) on Rheology and Workability Retention of Limestone Metakaolin Blended Cement." Presented at the *1st RILEM Youth Symposium (RYS2025)*. Virtual: RILEM Youth Council.

10. Tran, T. 2025. "Effects of Superplasticizers on Rheology and Workability Retention of Limestone Metakaolin Blended Cement." Presented at the *ACI Concrete Convention*. Toronto, ON, Canada: American Concrete Institute.

11. Tran, T. 2025. "Effects of Workability Modifiers Blending on Fresh Properties of Limestone Metakaolin Blended Cement." Presented at the *Carbon Conscious Concrete Symposium (C3 2025)*. Chicago, IL: C3 Symposium.

12. Wang, K. 2025. "Performance and Durability of Pavement Concrete with LC^3-Inspired Blended Binders." Presented at the *Workshop on Advanced Technologies and Decarbonization Strategies for High-Performance Concrete*. São Paulo, Brazil: University of São Paulo.

Submitted for Publication or Presentation

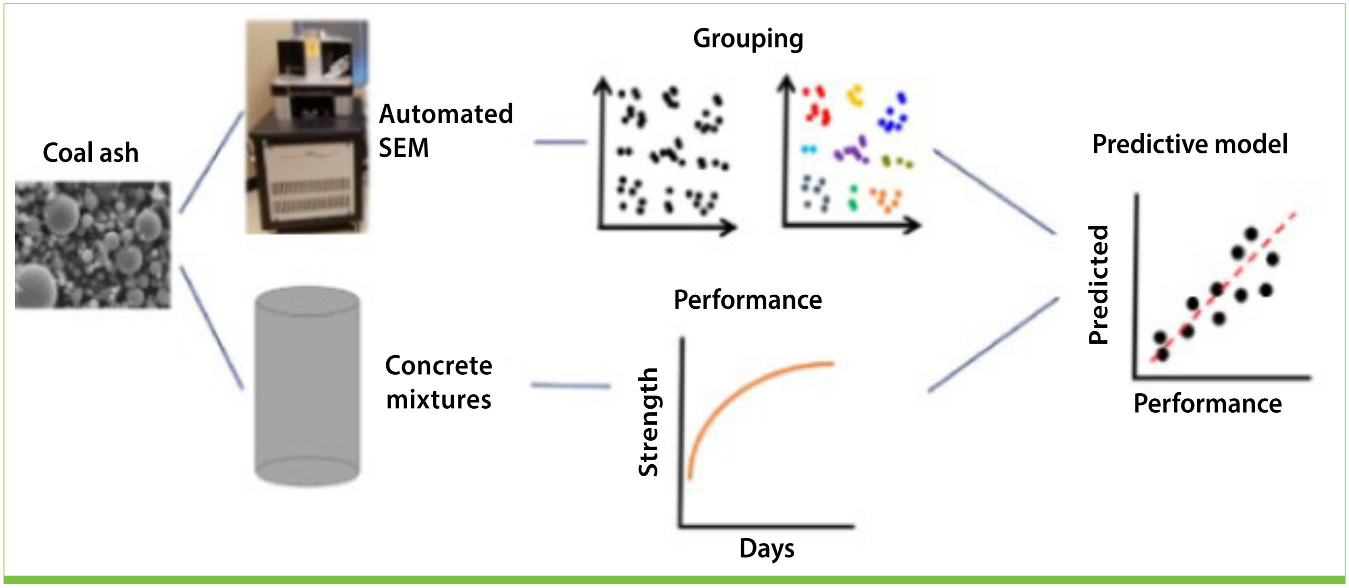
1. Kurtis, K. 2025. "Development of LC^3-Like Blends Using U.S. Regional Materials." Submitted for the *ACI Concrete Convention*. Chicago, IL: American Concrete Institute.

2. Kurtis, K. 2025. "Machine Learning-Assisted Optimization of LC^3 Systems." Submitted for presentation at the *ICCCSC (International Conference on Calcined Clay for Sustainable Concrete)*. Cape Town, South Africa: The International Union of Laboratories and Experts in Construction Materials, Systems and Structures.

3. Luo, D., M. Juenger, K. Kurtis, K. Riding, P. Taylor, and K. Wang. 2025. "Properties of Blended Binder Concrete Made with U.S. Regional Type IL Cement, Calcined Clay, and Limestone Powder." Under review by *ACI Materials Journal*.

4. Riding, K. 2025. "That's Hot! Calcined Clay Use in Thermally Controlled Concrete Placements." Submitted for presentation at the *ACI Concrete Convention*. Chicago, IL: American Concrete Institute.

5. Tran, T., P. Huynh, D. Benkeser, K. E. Kurtis, K. A. Riding, K. Wang, and M. C. G. Juenger. 2025. "Performance Evaluation of U.S. Regional Portland Limestone Cement–Calcined Clay Blends." Under review by *ACI Materials Journal*.



SEM = scanning electron microscope.
Schematic of the overall predictive model procedure for the study.[8]

PERFORMANCE-BASED CLASSIFICATION METHODS FOR HARVESTED COAL ASH

Oklahoma State University; Georgia Tech Research Corporation; Ohio State University; and Diversified Engineering Services, Inc.

Researchers studied older coal ash from landfills and surface impoundments, called harvested coal ash, to determine whether these sources provide viable alternatives to the approved coal ash sources currently in use. The researchers sought to combine advanced material characterization methods, performance-based testing, mechanistic modeling, and machine learning (ML) to create engineering tools for classifying harvested coal ash.[7] The project involved tweaking existing testing methods to analyze harvested coal ash performance when used for concrete production. The researchers wanted to capture the differences in chemical composition among the various harvested coal ashes and how those differences relate to their performance in concrete. The team also used ML to analyze the test data to see what patterns emerged.

Published

Parastegari, N., T. Ley, A. Behravan, and S. Kang. 2025. "Predicting Long-Term Changes in the Diffusion Coefficient of Fly Ash Mixtures." *Innovative Infrastructure Solutions* 10: 391. https://doi.org/10.1007/s41062-025-02151-2, last accessed November 18, 2025.

ARTIFICIAL INTELLIGENCE

ADVANCED ARTIFICIAL INTELLIGENCE RESEARCH FOR SAFETY OF VULNERABLE ROAD USERS

University of Tennessee at Chattanooga, University of Arizona, and University of San Francisco

This project aims to develop a safe, AI-based, flexible (SAIFE) system that can identify and track vulnerable road users (VRUs) (i.e., any road user not in a motor vehicle with a protected outside shield, such as pedestrians, cyclists, and wheelchair users) and prevent potential vehicle−VRU collisions at intersections.[9] The SAIFE system project aims to detect, classify, and track VRUs at intersections while enhancing resiliency against sensor failure. This system will use various real-time sensors to create sensor-fusion algorithms for accurately classifying VRUs. The SAIFE system will then perform AI-based multiple-object tracking and trajectory prediction, thereby facilitating situational awareness, such as automated conflict and risk assessments.

Published or Presented

1. Bang, T., H. H. Nguyen, D. S. Depto, L. Cheng, L. Guo, S. Cao, T. Zhang, A. Harris, and M. Sartipi. 2025. "Real-Time Edge-Based Multi-Sensor Fusion for Vulnerable Road User Safety at Urban Intersections." Poster presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

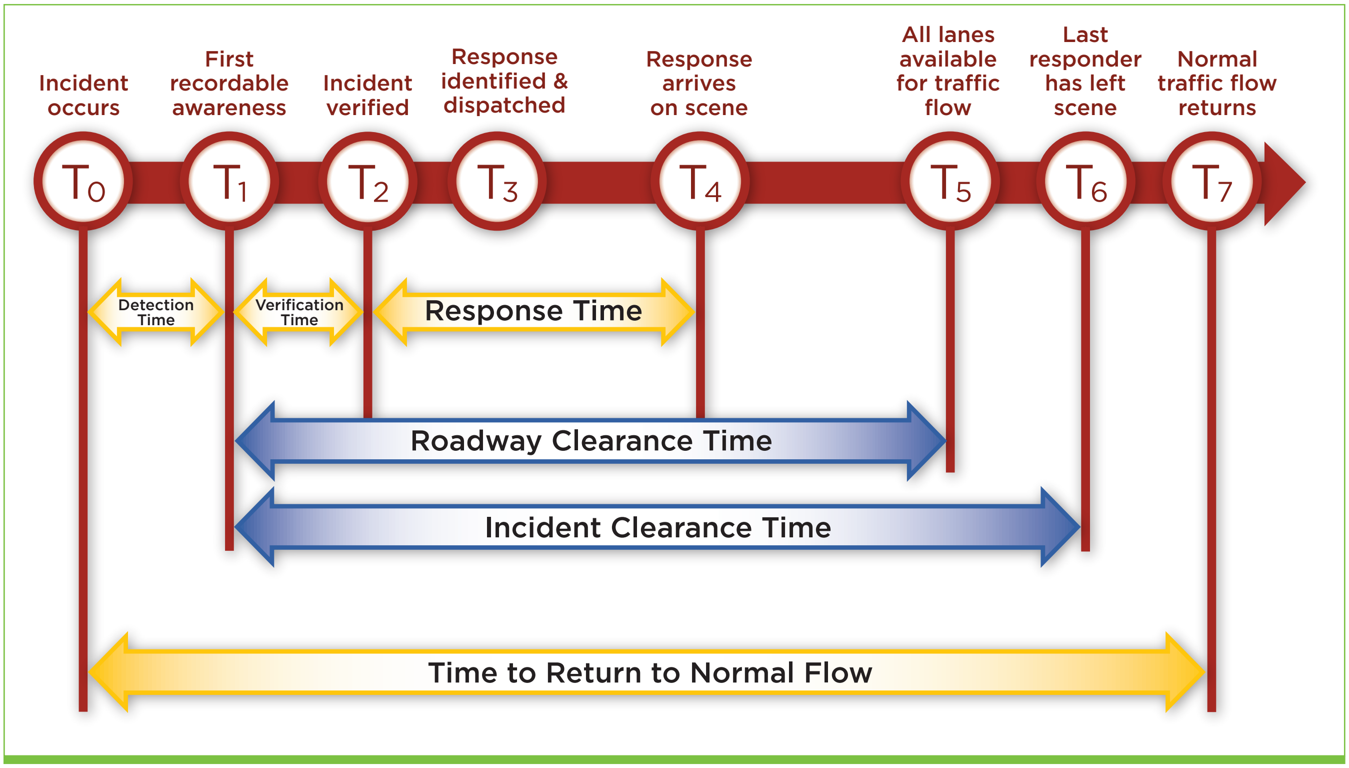
2. Cheng, L., L. Guo, T. Zhang, T. Bang, A. Harris, M. Hajij, M. Sartipi, and S. Cao. 2025. "CalibRefine: Deep Learning-Based Online Automatic Targetless LiDAR–Camera Calibration With Iterative and Attention-Driven Post-Refinement." *IEEE Transactions on Instrumentation and Measurement* 75: 1–18. https://doi.org/10.1109/TIM.2025.3647989, last accessed February 6, 2026.

3. Zhang, T., L. Cheng, T. Bang, L. Guo, M. Hajij, S. Cao, A. Harris, and M. Sartipi. 2025. "Roadside Sensor Systems for Vulnerable Road User Protection: A Review of Methods and Applications." *IEEE Access* 13: 62717–62738.

PREDICTIVE REAL-TIME TRAFFIC MANAGEMENT IN LARGE-SCALE NETWORKS USING MODEL-BASED ARTIFICIAL INTELLIGENCE

Carnegie Mellon University and University of Washington, Seattle

Despite decades of research, mitigating traffic congestion from nonrecurring causes, such as crashes, disabled vehicles, and adverse weather events, remains quite difficult for highway system operations practitioners.[10] This work needs an automated process of accurate, real-time prediction and proactive operational management that does not yet exist. For this project, researchers from Carnegie Mellon University and the University of Washington aimed to address this issue. The researchers sought to fuse prediction strategies, based on artificial intelligence (AI) and ML guided by transportation network flow models, with operational strategies. The researchers wanted to predict nonrecurrent traffic conditions in large-scale networks up to 30 min



Source: FHWA.

Incident management timeline.[11]

ahead of the earliest time an incident is reported and proactively recommend real-time operational management strategies.

Published or Presented

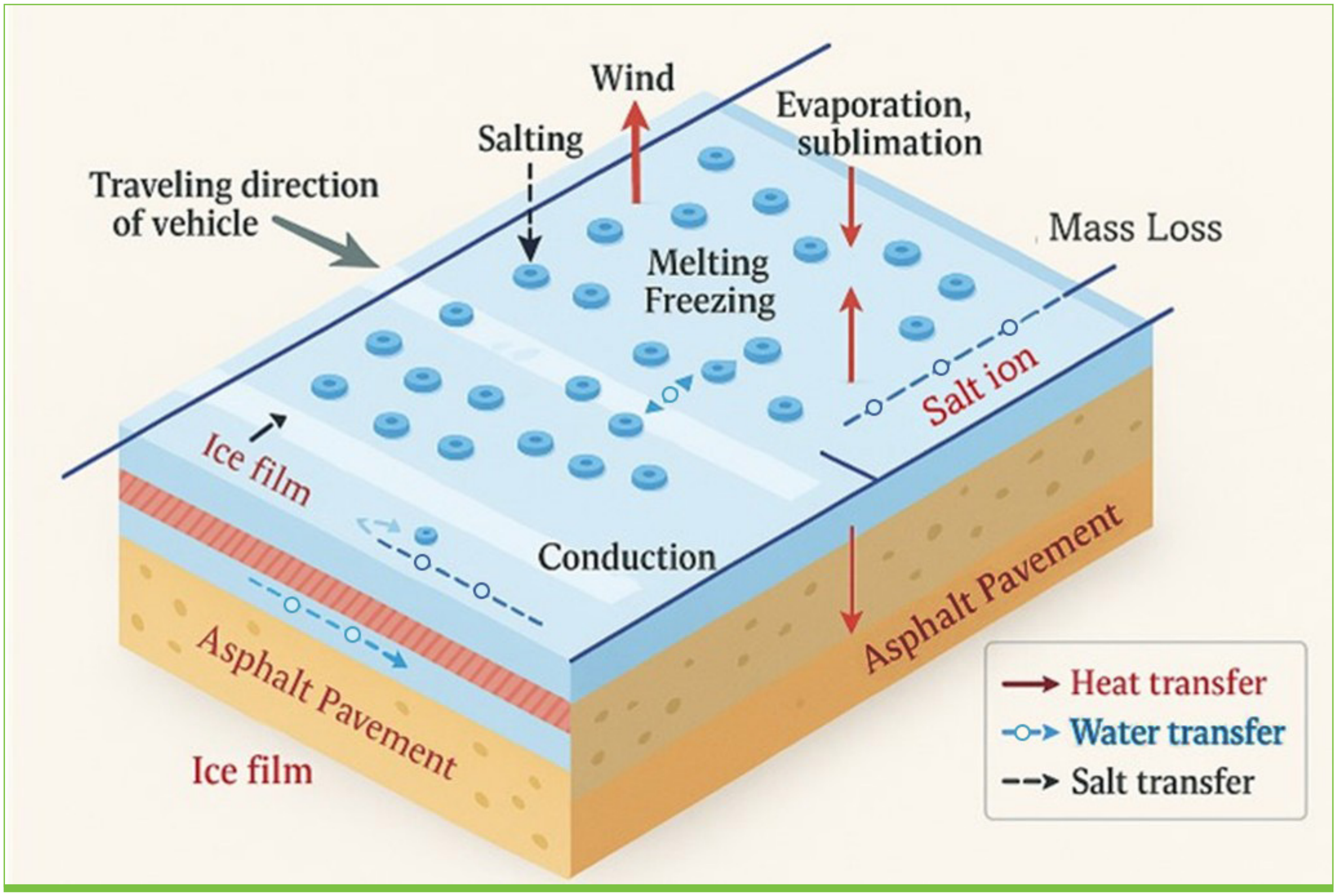
1. Duan, H., and S. Qian. 2025. “Know Unreported Roadway Incidents in Real-Time: Early Traffic Anomaly Detection.” Presented at the *Transportation Research Board Annual Meeting 2025*. Washington, DC: Transportation Research Board. Under review for publication in *Transportation Research Part C*.

2. Ke, Z., Q. Zou, J. Liu, and S. Qian. 2025. “Real-Time System Optimal Traffic Routing Under Uncertainties—Can Physics Models Boost Reinforcement Learning?” *Transportation Research Part C: Emerging Technologies* 173: 105040. https://doi.org/10.1016/j.trc.2025.105040, last accessed November 19, 2025.

AUTONOMOUS WINTER ROAD MAINTENANCE DECISIONMAKING ENABLED BY BOOSTING EXISTING TRANSPORTATION DATA INFRASTRUCTURE WITH DEEP AND REINFORCEMENT LEARNING

Michigan Technological University and University of Virginia

Researchers at Michigan Technological University investigated the potential to shift winter maintenance decisionmaking from a model-driven to an AI-enhanced framework.[12] The researchers developed a data-driven maintenance decision support system to help State department of transportation (DOT) highway maintenance professionals plan for weather events through improved data processing, predictive road condition methods, and computer-supported



Dynamics of snow, ice, water, and salt on a winter road surface.

Artificial Intelligence

decisionmaking. The team investigated opportunities from AI to analyze real-world situations in realtime. Recurrent neural networks (RNNs) and road condition predictions provided a data-driven environment. Deep reinforced learning took the RNN predictions and put them into action using ML to make autonomous decisions. Convolutional neural networks provided real-time road condition sensing. To test these ML models in the field, researchers worked with the Michigan DOT and Michigan county road agencies to conduct field tests. The researchers developed a closed-loop approach consisting of data gathering, condition predictions, decisionmaking, validation, and human intervention. This approach maximized AI's capability to significantly improve winter maintenance operations, safety, and mobility; reduce labor hours and costs; and indirectly enhance pavement design and management.

Published or Presented

1. Dastjerdi, M. H. T., A. Golalipour, and Z. Liu. 2025. "Comprehensive Winter Road Surface Model: Integrating Snow, Ice, Water, and Maintenance Dynamics." Accepted for podium presentation at the *17th World Congress on Road Winter Service, Resilience, and Decarbonisation*. Chambery, France: World Road Association (PIARC).

2. Dastjerdi, M. H. T., A. Golalipour, and Z. Liu. 2025. "Comprehensive Winter Road Surface Model: Integrating Snow, Ice, Water, and Maintenance Dynamics." Accepted for poster presentation at the *17th World Congress on Road Winter Service, Resilience, and Decarbonisation*. Chambery, France: PIARC.

3. Dastjerdi, M. H. T., A. Golalipour, and Z. Liu. 2025. "Incorporating Human Feedback to Refine Reinforcement Learning for Winter Road Maintenance." Accepted for the *IRF Global R2T Conference & Exhibition*. Long Beach, CA: International Road Federation.

4. Dastjerdi, M. H. T., A. Golalipour, and Z. Liu. 2025. "A Reinforcement Learning Framework for Optimizing Winter Road Maintenance Using Deep Q-Networks." Accepted for poster presentation at the *17th World Congress on Road Winter Service, Resilience, and Decarbonisation*. Chambery, France: PIARC.

5. Liu, M. 2025. "Extending Road Weather Information System for Counties." Presented at the *North American Snow Conference*. Grand Rapids, MI: American Public Works Association.

6. Liu, M., B. Azmoon, M. H. T. Dastjerdi, A. Biniyaz, and Z. Liu. 2025. "Spring Load Restriction Methods: A Comprehensive Review." *Transportation Geotechnics* 51: 101532.

7. Liu, M., M. H. T. Dastjerdi, Y. Ren, and Z. Liu. 2025. "Real-Time Assessment of Pavement Resilient Modulus Through Field Monitoring and Three-Stage Constitutive Modeling for Seasonal Weight Restrictions." Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

8. Liu, Z. 2025. *Artificial Intelligence for Engineers: Basics and Implementations*. New York, NY: Springer.

9. Liu, Z. 2025. "Use of AI and Data for Autonomous Winter Maintenance Decision: Part I: Overview." Presented at the *North American Snow Conference*. Grand Rapids, MI: American Public Works Association.

10. Liu, Z. 2025. "Use of AI and Data for Autonomous Winter Maintenance Decision: Part II: Demo and Panel Discussion." Presented at the *North American Snow Conference*. Grand Rapids, MI: American Public Works Association.

11. Tavakoli, H. 2025. "Improvement of the Resiliency Via More Proactive Winter Maintenance." Presented at the *North American Snow Conference*. Grand Rapids, MI: American Public Works Association.

Submitted for Publication or Presentation

1. Liu, M., Y. Ren, M. H. T. Dastjerdi, A. Biniyaz, and Z. Liu. 2025. "Saturated-Unsaturated Poroelasticity Framework for Coupled Seepage and Deformation Analysis: Numerical Implementation and Validation Against Lab Tests." Submitted to *Computer and Geotechnics*.

2. Ren, Y., Z. Liu, and M. Liu. 2025. "In-Poro: Differentiable Inverse Analysis Framework for Poroelasticity." Submitted to *Computer and Geotechnics*.

3. Ren, Y., Z. Liu, and M. Liu. 2025. "Poro-CRNet: A CNN-Based Physics-Informed Neural Network for Poroelasticity." Submitted to *Acta Geotechnica*.

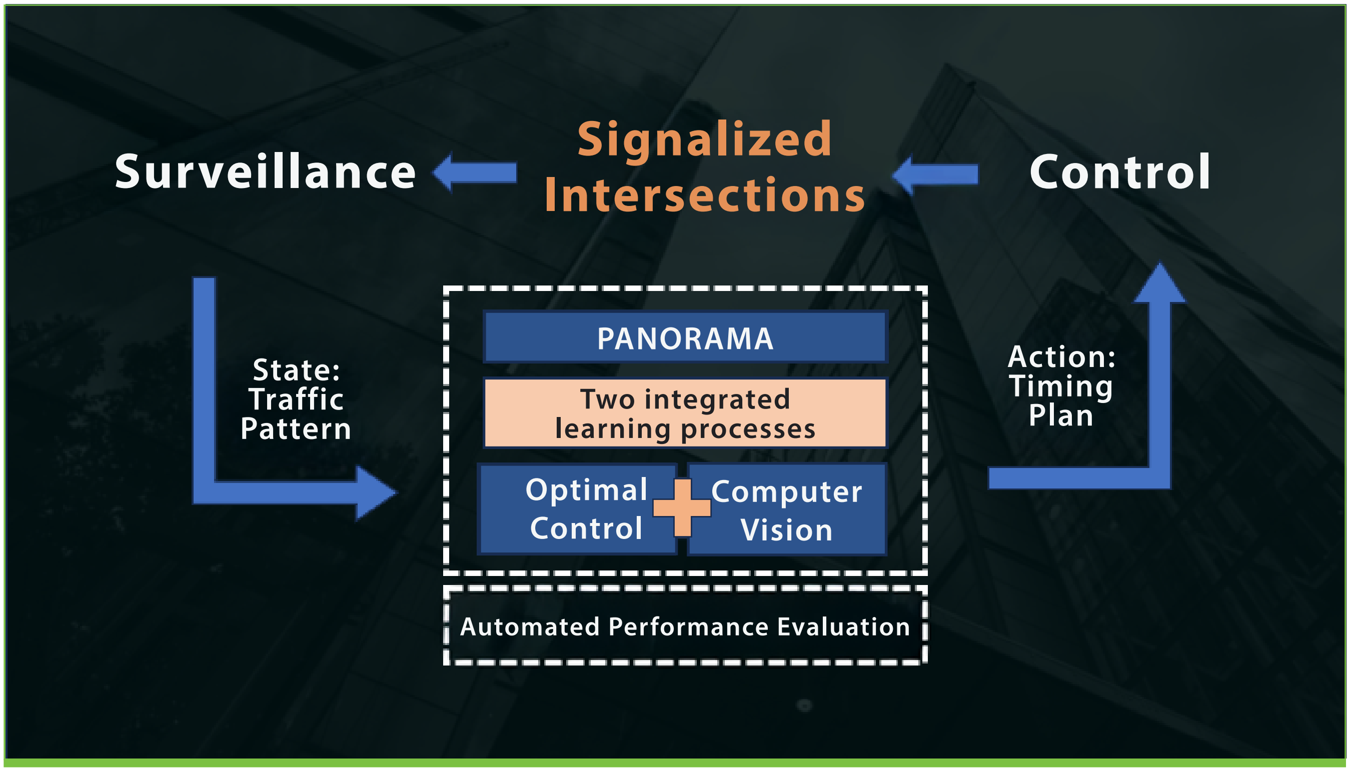
PANORAMA: AN INTERPRETABLE CONTEXT-AWARE AI FRAMEWORK FOR INTEGRATED REAL-TIME INTERSECTION DETECTION AND SIGNAL OPTIMIZATION

Southern Methodist University,
Georgia Institute of Technology, and
University of Tulsa

For this study, the researchers are developing an AI system that detects VRUs and adjusts traffic signal timing at intersections.[9] The PANORAMA system integrates real-time user intersection detection and traffic signal control optimization into a single AI framework. This system's architecture includes several AI learning modules that enable it to optimize its user detection and traffic signal control decisions based on data input and real-time experience. These modules make the system adaptable to changing operational environments and conditions. The PANORAMA project draws on research developments in adaptive signal control with advanced detection, AI domain adaptation, and interpretable reinforcement learning and control. PANORAMA is expected to enhance transportation system efficiency, improve safety, and reduce construction and operation costs.

Submitted for Publication

Younas, Z., K. Abdelghany, M. Hunter, and M. Khodayar. 2025. "Traffic Object Detection Across Diverse Environmental Conditions: A Comparative Performance Evaluation of Computer Vision Models." Under review for publication in the *Transportation Research Record*.



Overview of PANORAMA system architecture.[9]

INFRASTRUCTURE EVALUATION AND MANAGEMENT

COST-EFFICIENT NETWORK-LEVEL PAVEMENT MANAGEMENT FRAMEWORK FOR FLEXIBLE PAVEMENT PRESERVATION AND MAINTENANCE

University of Massachusetts Amherst and Total Environmental Service Technologies, Inc.

The research team for this project is focusing on developing an economic analysis methodology for network-level pavement management. The framework emphasizes lifecycle cost analysis to identify the impact of different maintenance strategies that minimize both agency and user costs, reduce material consumption, and maximize economic efficiency. The researchers are investigating the cost effectiveness of maintaining pavements at various performance levels to allow for quantifying the tradeoffs between initial investment and the costs of long-term maintenance, vehicle operation, safety, travel time, and material resources. The outcome of this project will assist State DOTs and local agencies with maintaining their transportation infrastructure efficiently and cost effectively, saving taxpayer dollars.

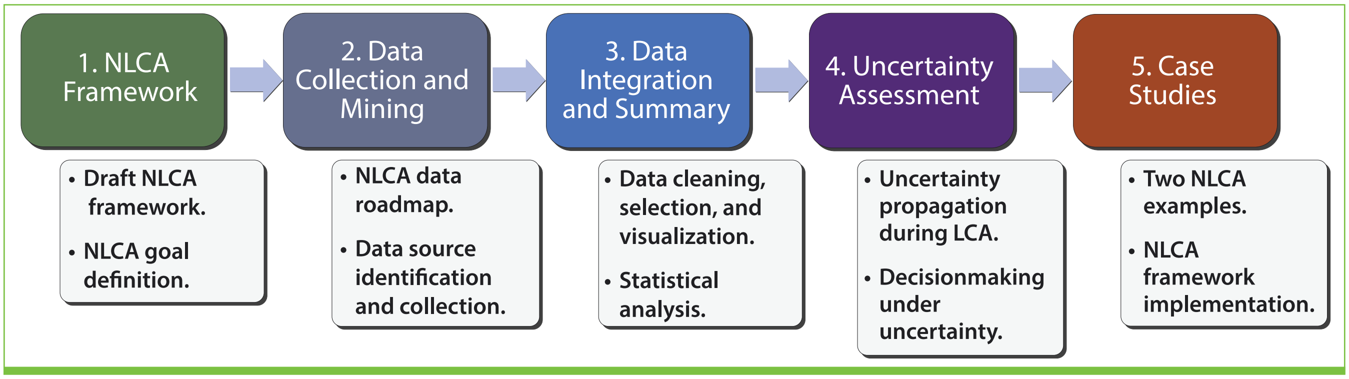
Published or Presented

1. Mostatab, S., U. S. Yildirim, E. Okte, E. Tseng, H. Ozer, and I. L. Al-Qadi. 2025. "Stochastic Network-Level Pavement Life Cycle Assessment Framework Development." In *Airfield and Highway Pavements 2025*. Reston, VA: American Society of Civil Engineers.
2. Yildirim, U. S., S. Mostatab, M. Zeigham, E. Okte, E. Tseng, H. Ozer, and I. L. Al-Qadi. 2025. "Integration of Network Level Life-Cycle Cost Analysis in Pavement Management Systems." Presented at the *Transportation Research Board Annual Meeting 2026*. Washington, DC: Transportation Research Board.

ADVANCED VISION-BASED ASSESSMENT OF INFRASTRUCTURE SYSTEMS

University of Texas at Austin

Assessing reinforced concrete structures for cracking, crack widths, patterns, and orientations usually involves some visual inspection. A research team at the University of Texas at Austin is developing technologies to help with visual bridge component inspection.[14] This project is creating a new, mixed-reality visual inspection system that uses a pair of virtual reality (VR) goggles to overlay what the human eye sees when surveying bridge components for maintenance needs. A computational tool that incorporates ML will also perform structural diagnostics decisionmaking for the system. This AI-enhanced decisionmaking will provide the inspector wearing the VR goggles with information (e.g., crack lengths, crack widths, patterns, and orientations) represented by virtual images in the inspector's field of sight. The computational tool will be able to organize data captured from multiple sources and determine relationships between elements of those data.



LCA = lifecycle assessment; NLCA = network-level LCA.

An infographic illustrating the five-step, network-level lifecycle assessment process.[13]

Published or Presented

1. Pantoja-Rosero, B. G., and S. Salamone. 2025. "Integrating Extended Reality and AI-Based Damage Segmentation for Near Real-Time, Traceable Bridge Inspections." *Automation in Construction* 180: 106567. https://www.sciencedirect.com/science/article/pii/S0926580525006077, last accessed November 21, 2025.

2. Shamszadeh, M. M., K. Kumar, A.-C. Ferche, O. Bayrak, and S. Salamone. 2026. "Explainable Boosting Machine for Structural Health Assessment of Reinforced Concrete Beams Using Crack Width Measurements." *Automation in Construction* 181, part B: 106641. https://www.sciencedirect.com/science/article/pii/S0926580525006818?dgcid=author, last accessed November 21, 2025.

ARTIFICIAL INTELLIGENCE APPROACHES TO MULTI-OBJECT EVALUATION OF PAVEMENTS FOR CONDITION AND SAFETY

Oklahoma State University and University of Maryland

This project is developing novel approaches to pavement engineering while increasing safety.[(15)] The research team is combining AI methods with three-dimensional (3D) laser imaging to transform how pavements are evaluated for real-time condition and safety assessment. By applying deep learning architectures to high-resolution, noncontact laser data, the system can identify multiple pavement distresses (such as cracks, potholes, and patching) in a single pass while also quantifying surface texture for roadway safety evaluation. Unlike traditional methods that rely on contact-based or water-based devices, this noncontact approach enables continuous, accurate, and repeatable surveys at highway speed, reducing costs and improving reliability. The outcome of this research will provide a foundation for future pavement safety evaluation standards, equipping transportation agencies with robust tools for better-informed maintenance and safety decisions.

Published or Presented

1. Ansari, F., K. Chatterjee, J. Q. Li, K. Wang, and A. Golalipour. 2025. "Multi-Object Pavement Surface Feature Detection with CNN and Transformer Deep Learning Architecture." In *Airfield and Highway Pavements 2025*. Reston, VA: American Society of Civil Engineers. https://doi.org/10.1061/9780784486214.032, last accessed November 24, 2025.

2. Ansari, F., J. Q. Li, K. Wang, and A. Golalipour. 2025. "Intelligent Pavement Feature Detection Using Deep-Learning Multimodal Approaches." Poster presented at the *2025 Annual Road Profile Users' Group (RPUG) Conference*. Dallas, TX: Road Profile Users' Group.

3. Ansari, F., J. Liu, J. Q. Li, and A. Golalipour. 2025. "Artificial Intelligence Approach for Multi-Object Pavement Condition Evaluation." Poster presented at the *2025 Oklahoma Transportation Research Day*. Oklahoma City, OK: Southern Plains Transportation Center.

4. Ansari, F., J. Q. Li, K. Wang, and A. Golalipour. 2025. "Artificial Intelligence Approaches for Multi-Object Pavement Condition Evaluation." Presented at the *IRF Global R2T Conference & Exhibition*. Long Beach, CA: International Road Federation.

5. Wang, G., K. C. P. Wang, G. Yang, J. Q. Li, and A. Golalipour. 2025. "Signal Noise Estimation and Removal of Sub-mm 3D Pavement Texture Data Using 1D Residual Denoising Network." *Computer-Aided Civil and Infrastructure Engineering*. 40, no. 20: 3033–3052. https://doi.org/10.1111/mice.13502, last accessed November 24, 2025.

Submitted for Publication

1. Ansari, F., J. Q. Li, G. Wang, K. Wang, and A. Golalipour. 2025. "Pavement Safety Evaluation Using Deep Learning and Non-Contact Super-Resolution Texture Measurements at Highway Speed." Submitted to the *ASCE Journal of Transportation Engineering, Part B: Pavements*.

2. Liu, J., K. Parajulee, J. Q. Li, and A. Golalipour. 2025. "Pavement Surface Distress Detection Based on Deep Learning: A Systematic Review." Submitted to *Sensors*.

INTERAGENCY RESEARCH

The following projects were jointly funded by the FHWA EAR Program and the National Science Foundation (NSF).

IDENTIFYING, CHARACTERIZING, AND SHAPING MULTI-SCALE CYBER-HUMAN INTERACTIONS

University of Wisconsin-Madison

Researchers at the University of Wisconsin-Madison explored what makes human drivers lose trust in vehicle automation, leading the driver to intervene unnecessarily. The researchers investigated scenarios that included human drivers in both fully automated and manually controlled vehicles and how erroneous human interventions could negatively impact traffic flow. With more automated vehicles on the roadways in the upcoming decades, researchers are interested in increasing trust in automated vehicles, which would then help improve traffic flow. In the first phase of the project, the researchers used a driving simulator and software to simulate traffic, providing the capability to test automated vehicle algorithms and human-driven vehicle simulations safely and efficiently. Then, the researchers designed experiments to include human participants in controlled field tests. (NSF Award CNS 1739869)

Published

1. Jiang, J., Y. Zhou, G. Jafarsalehi, X. Wang, S. Ahn, and J. D. Lee. 2025. "Stochastic Calibration of Automated Vehicle Car-Following Control: An Approximate Bayesian Computation Approach." *IEEE Transactions on Intelligent Transportation Systems* 26, no. 3: 3115–3127. https://doi.org/10.1109/TITS.2025.3526318, last accessed December 16, 2025.

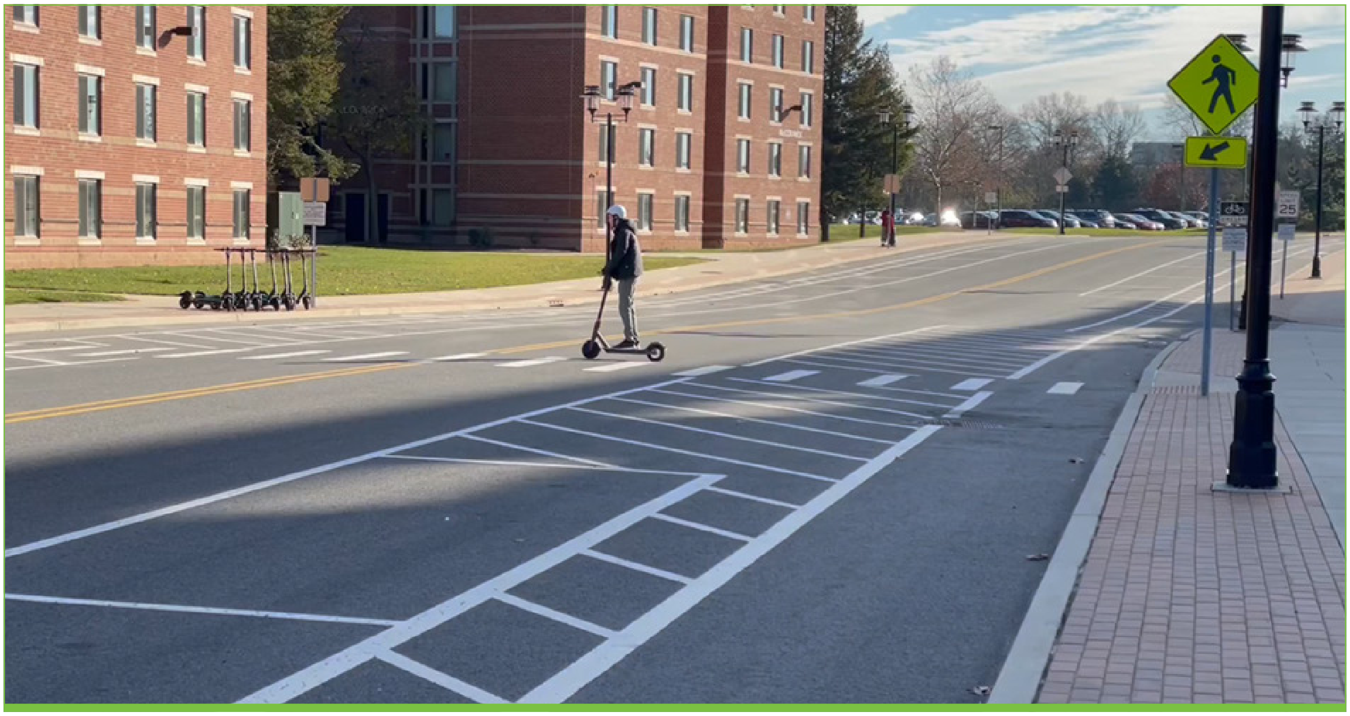
2. Jiang, J., Y. Zhou, X. Wang, and S. Ahn. 2024. "A Generic Stochastic Hybrid Car-Following Model Based on Approximate Bayesian Computation." *Transportation Research Part C: Emerging Technologies* 167: 104799. https://doi.org/10.1016/j.trc.2024.104799, last accessed December 16, 2025.

3. Zhong, X., Y. Zhou, A. V. Kamaraj, Z. Zhou, W. Kontar, D. Negrut, J. D. Lee, and S. Ahn. 2025. "Human-Automated Vehicle Interactions: Voluntary Driver Intervention in Car-Following." *Transportation Research Part C: Emerging Technologies* 171: 104969. https://doi.org/10.1016/j.trc.2024.104969, last accessed December 16, 2025.

MAKING MICROMOBILITY SMARTER AND SAFER

Rutgers University

The growth of micromobility vehicles (transportation devices such as pedal-driven and electric-assist bicycles and electric-assist scooters) in the United States over the past decade has been staggering.(16) From 2010 to 2019, shared micromobility vehicle ridership ballooned from 321,000 trips annually in 2010 to 136 million annually in 2019.(17) In 2020, travelers in the United States took an estimated 67.9 million trips on shared micromobility vehicles.(18) Driven by the rise of shared rentals deployed by municipalities and private companies, micromobility vehicles have become a popular transportation alternative for individuals in cities and, increasingly, in smaller towns and suburbs throughout the Nation. The types of micromobility vehicles available for use have also increased. As a result, policymakers and researchers have grappled with the implications of this growing mode of transit. In particular, public safety for micromobility vehicle users, as well as the pedestrians and drivers they encounter, has become an increasing concern. For this project, the Rutgers University research team sought to gather better data and create technological tools to improve safety for pedestrians and micromobility vehicle users. (NSF Award CNS 1951890)



A person using an e-scooter to cross the street.[16]

Published

1. Ma, S., W. Zhang, R. B. Noland, and C. J. Andrews. 2024. "Eye Tracking Measures of Bicyclists' Behavior and Perception: A Systematic Review." *Transportation Research Part F: Traffic Psychology and Behavior* 107: 52–68. https://doi.org/10.1016/j.trf.2024.08.026, last accessed December 16, 2025.

2. Tan, H., Y. Yuan, H. Yan, S. Zhong, and Y. Yang. 2024. "Human Preference-Aware Rebalancing and Charging for Shared Electric Micromobility Vehicles." In *2024 IEEE International Conference on Robotics and Automation (ICRA)*. New York, NY: IEEE. https://doi.org/10.1109/ICRA57147.2024.10610713, last accessed December 16, 2025.

3. Younes, H., C. Andrews, R. B. Noland, J. Xia, S. Wen, W. Zhang, D. Metaxas, L. A. Von Hagen, and J. Gong. 2024. "The Traffic Calming Effect of Delineated Bicycle Lanes." *Journal of Urban Mobility* 5: 100071. https://doi.org/10.1016/j.urbmob.2024.100071, last accessed December 16, 2025.

HYBRID TWINS FOR URBAN TRANSPORTATION: FROM INTERSECTIONS TO CITYWIDE MANAGEMENT

Columbia University

Traffic management in metropolitan areas poses distinct challenges.[19] Faced with congested city streets shared by pedestrians, bicyclists, electric-scooter riders, and drivers, traffic managers must find new ways to maintain smooth and safe traffic flow. Traffic managers can harness the data collected by electronic devices that connect to the Internet, infrastructural sensors, other devices or systems, and communications networks in the Internet of Things (IoT) to transform urban streets. This research project leverages the IoT to develop an urban traffic management system that will help improve traffic safety, mobility, and reliability. To explore the possibilities of this advanced traffic management system, the research team at Columbia University is creating a hybrid twin of an area of New York City, NY. (NSF Award CNS 2038984)

Published

1. Fu, Y., A. Jain, X. Chen, Z. Mo, and X. Di. 2024. "DriveGenVLM: Real-World Video Generation for Vision Language Model Based Autonomous Driving." In *2024 IEEE International Automated Vehicle Validation Conference (IAVVC)*. New York, NY: IEEE, pp. 1–6. https://ieeexplore.ieee.org/document/10786438/, last accessed December 16, 2025.

2. Huang, K., and Q. Du. 2024. "Asymptotic Compatibility of a Class of Numerical Schemes for a Nonlocal Traffic Flow Model." *SIAM Journal on Numerical Analysis* 62, no. 3. https://doi.org/10.1137/23M154488X, last accessed December 16, 2025.

3. Pargoo, N. S., M. Ghasemi, S. Xia, M. K. Turkcan, T. Ehsan, C. Zang, Y. Sun, et al. 2025. "Urban Sensing for Human-Centered Systems: A Modular Edge Framework for Real-Time Interaction." In *HumanSys '25: Proceedings of the 3rd International Workshop on Human-Centered Sensing, Modeling, and Intelligent Systems*. New York, NY: Association for Computing Machinery, pp. 92–97. https://doi.org/10.1145/3722570.3726890, last accessed December 16, 2025.

RESEARCH STANDARDS AND TECHNICAL ASSESSMENT SUPPORT

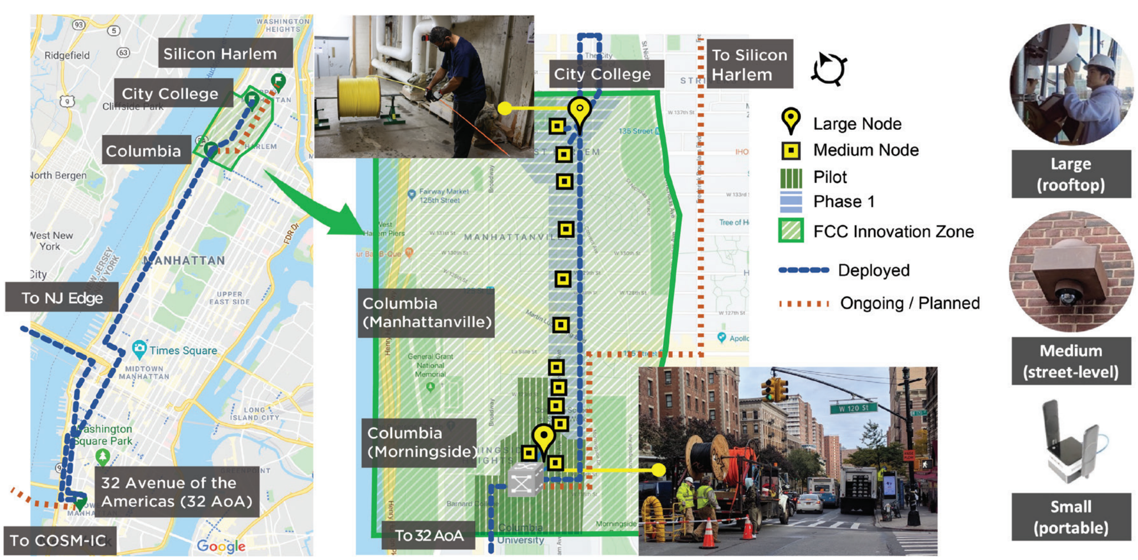
Oak Ridge National Laboratory

Researchers at Oak Ridge National Laboratory developed calibration and measurement techniques to help the broader community of researchers wanting to work with Naturalistic Driving Study data. The techniques they employed in this study enabled benchmarking progress and technical assessment of EAR Program-sponsored research teams.

Published

1. Khattak, Z. H., W. Li, T. Karnowski, and A. J. Khattak. 2024. "The Role of Driver Head Pose Dynamics and Instantaneous Driving in Safety Critical Events: Application of Computer Vision in Naturalistic Driving." *Accident Analysis & Prevention* 200: 107545.

2. Peruski, R., D. Aykac, L. Torkelson, and T. Karnowski. 2024. "Exploring Object Detection and Image Classification Tasks for Niche Use Case in Naturalistic Driving Studies." *Electronic Imaging* 36: 1–6.



Phase 1 deployment.[19]

REFERENCES

1. FHWA. 2024. *Digital Twin-Enabled Extended Active Safety Analysis for Mixed Traffic*. Publication No. FHWA-HRT-24-054. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-054.pdf, last accessed November 24, 2025.

2. Scrivener, K., F. Avet, H. Maraghechi, F. Zunino, J. Ston, W. Hanpongpun, and A. Favier. 2019. “Impacting Factors and Properties of Limestone Calcined Clay Cements (LC3).” *Green Materials* 7, no. 1: 3–14. https://doi.org/10.1680/jgrma.18.00029, last accessed November 19, 2025.

3. Sharma, M., S. Bishnoi, F. Martirena, and K. Scrivener. 2021. “Limestone Calcined Clay Cement and Concrete: A State-of-the-Art Review.” *Cement and Concrete Research* 149: 106564.

4. Antoni, M., J. Rossen, F. Martirena, and K. Scrivener. 2012. “Cement Substitution by a Combination of Metakaolin and Limestone.” *Cement and Concrete Research* 42: 1579–1589.

5. Krishnan, S., A. C. Emmanuel, and S. Bishnoi. 2019. “Hydration and Phase Assemblage of Ternary Cements with Calcined Clay and Limestone.” *Construction and Building Materials* 222: 64–72. https://doi.org/10.1016/j.conbuildmat.2019.06.123, last accessed November 19, 2025.

6. FHWA. 2024. *Evaluating and Implementing CC-I-L Cement for the Next Generation of Concrete Bridge Construction*. Publication No. FHWA-HRT-24-057. Washington, DC: Federal Highway Administration. https://highways.dot.gov/media/51631, last accessed December 18, 2025.

7. FHWA. 2020. *Supplementary Cementitious Material Advancements: Helping to Make Longer Lasting Concrete Highways and Transportation Structures*. Publication No. FHWA-HRT-20-048. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/20048/20048.pdf, last accessed November 19, 2025.

8. Kang, S., M. T. Ley, Z. Lloyd, and T. Kim. 2020. “Using the Particle Model To Predict Electrical Resistivity Performance of Fly Ash in Concrete.” *Construction and Building Materials* 261: 119975.

9. FHWA. 2024. *Using Artificial Intelligence To Improve Safety for Vulnerable Road Users*. Publication No. FHWA-HRT-24-080. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-080.pdf, last accessed November 24, 2025.

10. FHWA. 2024. *Predictive Real-Time Traffic Management in Large-Scale Networks Using Model-Based Artificial Intelligence*. Publication No. FHWA-HRT-23-107. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-107.pdf, last accessed November 24, 2025.

11. Pecheux, K. K. 2016. *Process for Establishing, Implementing, and Institutionalizing a Traffic Incident Management Performance Measurement Program*. Report No. FHWA-HOP-15-028. Washington, DC: Federal Highway Administration. https://ops.fhwa.dot.gov/publications/fhwahop15028/fhwahop15028.pdf, last accessed June 3, 2025.

12. FHWA. 2021. *Implementation of Artificial Intelligence to Improve Winter Maintenance*. Publication No. FHWA-HRT-21-090. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/21090/21090.pdf, last accessed November 24, 2025.

13. FHWA. 2024. *Measuring Decarbonization in the Pavement Lifecycle*. Publication No. FHWA-HRT-24-056. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-056.pdf, last accessed November 24, 2025.

14. FHWA. 2025. *The Role of Artificial Intelligence and Machine Learning in Federally Supported Surface Transportation: 2024 Updates*. Report No. FHWA-HRT-25-020. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-25-020.pdf, last accessed November 21, 2025.

15. FHWA. 2024. *Using Artificial Intelligence to Evaluate Pavement Condition and Safety*. Publication No. FHWA-HRT-24-058. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-058.pdf, last accessed November 24, 2025.

16. FHWA. 2022. *Making Micromobility Smarter and Safer*. Publication No. FHWA-HRT-22-083. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-22-083.pdf, last accessed December 16, 2025.

17. National Association of City Transportation Officials. 2020. *Shared Micromobility in the US: 2019*. New York, NY: National Association of City Transportation Officials. https://nacto.org/shared-micromobility-2019/, last accessed December 16, 2025.

18. North American Bikeshare & Scootershare Association. 2021. *2nd Annual Shared Micromobility State of the Industry Report*. Portland, ME: North American Bikeshare and Scootershare Association.

19. FHWA. 2022. *Developing Future Traffic Management Systems Using Hybrid Twins*. Publication No. FHWA-HRT-22-089. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-22-089.pdf, last accessed December 16, 2025.

20. Google. 2022. Google Maps, Mountain View, CA. https://www.google.com/maps, last accessed August 15, 2022.

EAR Program Results

The EAR Program strives to develop partnerships with the public and private sectors because the very nature of the EAR Program is to apply ideas across traditional fields of research and stimulate new approaches to solving problems. 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 Program 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, and deepening vital research capacity.

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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.

The program has awarded 108 research projects on 59 different topics between 2007 and 2023. The research awards include work by multidisciplinary teams at 84 academic institutions, 58 private companies, 14 State and local agencies, 10 Federal laboratories, and 10 foreign institutions.

Learn More

For more information, see the EAR Program website at highways.dot.gov/research/programs/EAR. 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.

EXPLORATORY ADVANCED **RESEARCH**

U.S. Department of Transportation
Federal Highway Administration

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