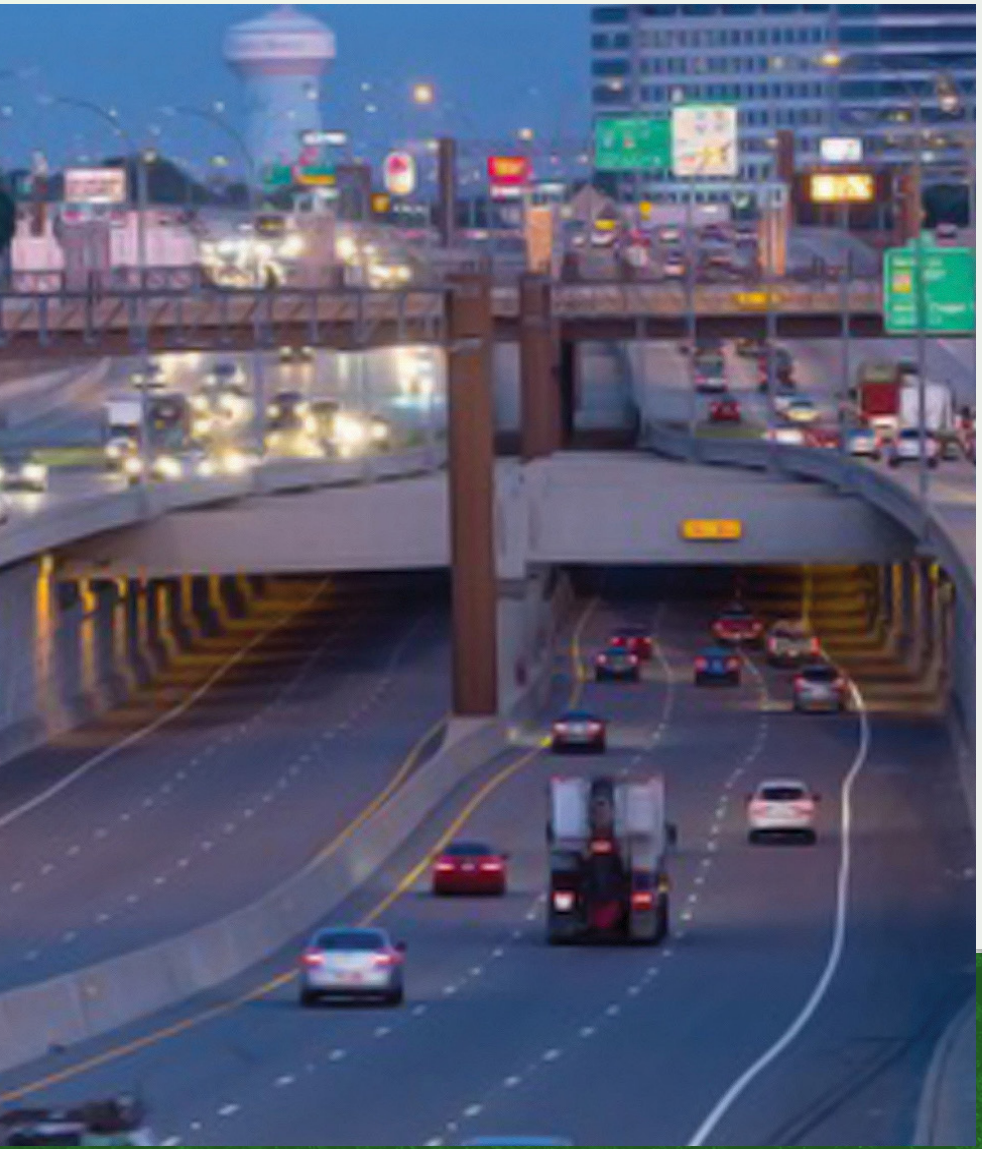
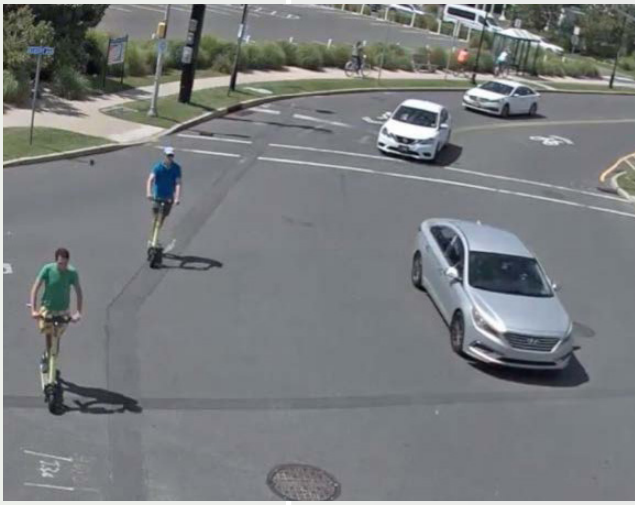
EXPLORATORY ADVANCED **RESEARCH**

EAR Program

Compendium of Papers From Funded Research Projects





U.S. Department of Transportation
Federal Highway Administration

Notice

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document. This report does not constitute a standard, specification, or regulation.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this document only because they are considered essential to the objective of the document.

All photos: Source: FHWA, unless otherwise noted.

Quality Assurance Statement

The Federal Highway Administration (FHWA) provides high-quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

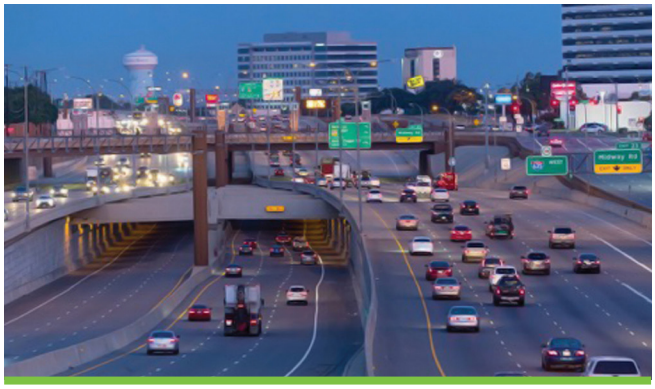
Cover photos

Clockwise:

Source: FHWA.

Contents

Behavioral Economics for Managed Lanes



© Texas A&M Transportation Institute. Traffic modeling relies on data from highways such as the Lyndon B Johnson Freeway in Dallas, TX.(1)

USING BEHAVIORAL ECONOMICS TO BETTER UNDERSTAND MANAGED LANE CHOICE

TEXAS A&M UNIVERSITY

Behavioral economics draws on insights from psychology and economics to better understand human decisionmaking.(1) Understanding cognitive biases and heuristics—such as loss aversion and present bias—may help policymakers predict human behavior and facilitate choices that support public benefits. Behavioral economists call these efforts to shape decisionmaking nudges—subtle tweaks to an environment that may influence human behavior. When applied to transportation studies, a behavioral economics framework can help develop more accurate models for predicting travelers' choices on the road and inform policy and transportation planning decisions. Researchers for the project Using Behavioral Economics to Better Understand Managed Lane Choice are evaluating how behavioral economics could improve travel demand models.

ACCEPTED FOR PUBLICATION

1. Ashraf, S., A. Brown, M. Burris, and V. Vitaku. 2023. "Aggregate and Individual Effects of Information in a Coordination (Traffic) Game." *Economic Inquiry* 61, no. 4: 818–850. https://doi.org/10.1111/ecin.13143, last accessed October 12, 2023.
2. Ashraf, S., M. Burris, A. Brown, and V. Vitaku. 2022. "Using Behavioral Economics to Identify Potential Managed Lane Users." *Transportation Research Record: Journal of the Transportation Research Board*, 2676, no.

Mobile Ad Hoc Networks

EXPLORING MOBILE AD HOC NETWORKS (MANETs) TO ENABLE CONNECTED TRANSPORTATION SERVICES

UNIVERSITY OF VIRGINIA

Researchers investigated the use of MANETs for a connected transportation system that meets the needs of all travelers. The researchers explored two scenarios where MANETs could be useful for enhancing road safety: pedestrians and cyclists crossing at the midblock in large groups (e.g., people leaving a sporting event or concert) and communication improvements in low-volume areas such as rural areas and national parks.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Liu, S., H. Shen, B. Smith, and V. Fessmann. 2023. "Machine Learning Based Intelligent Routing for VDTNs." *Proceedings of the 32nd International Conference on Computer Communications and Networks (ICCCN)*. New York, NY: IEEE, 1–10.

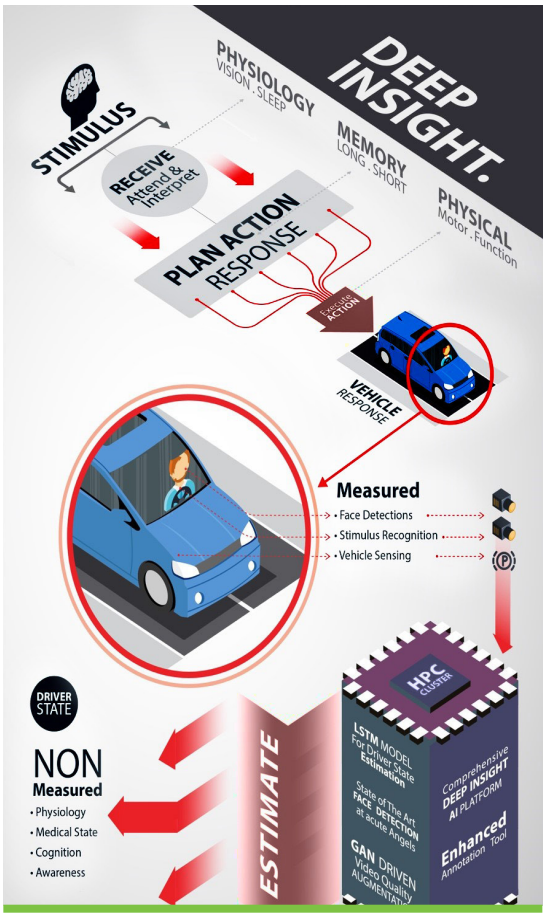
Computer Vision

DEEP INSIGHT: DEEP EXTRACTION OF DRIVER STATE FROM NATURALISTIC DRIVING DATASET

IOWA STATE UNIVERSITY, SYRACUSE UNIVERSITY, UNIVERSITY OF MISSOURI, AND UNIVERSITY OF NEBRASKA MEDICAL CENTER

For the project Deep InSight: Deep Extraction of Driver State from Naturalistic Driving Dataset, researchers designed a driver-state estimation platform to improve the capacity to analyze large datasets related to human driving behaviors.(2) This Deep InSight platform incorporated recurrent neural network (RNN) models trained to automatically detect and estimate human behaviors and deal with detection challenges, such as extreme-angle face detection when a driver is looking to the side or down. These RNNs are ideal for applications that involve complex interactions and input from multiple sensors, crucial for automated evaluation of driver state.

Evaluating driver state requires tracking combinations of cues over many frames—from multiple camera views—and merging those with vehicle sensor data over time. The platform also makes it easier for researchers to manually check those automated annotations and verify the model's performance.



© REACTOR Lab. Deep InSight platform design including tools and stages.[2]

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Aboah, A., Y. Adu-Gyamfi, S. V. Gursoy, J. Merickel, M. Rizzo, and A. Sharma. 2023. "Driver Maneuver Detection and Analysis Using Time Series Segmentation and Classification." *Journal of Transportation Engineering, Part A: Systems* 149, no. 3. https://doi.org/10.1061/JTEPBS.TEENG-7312, last accessed October 4, 2023.
2. Chai, W., J. Chen, J. Wang, S. Velipasalar, A. Venkatachalapathy, Y. Adu-Gyamfi, J. Merickel, and A. Sharma. 2023. "Driver Head Pose Detection from Naturalistic Driving Data." *IEEE Transactions on Intelligent Transportation Systems* 24, no. 9: 9368–9377. https://doi.org/10.1109/TITS.2023.3275070, last accessed October 4, 2023.
3. Hasan, M. Z., A. Joshi, M. Rahman, A. Venkatachalapathy, A. Sharma, C. Hegde, and S. Srakar. 2022. "DriveCLIP: Zero-Shot Transfer for Distracted Driving Activity Understanding Using CLIP." Presented at *Machine Learning for Autonomous Driving Workshop at the 36th Conference on Neural Information Processing Systems (NeurIPS 2022)*. New Orleans, LA: Neural Information Processing Systems. https://dr.lib.iastate.edu/server/api/core/bitstreams/6caedeff-3a7d-46bc-aa80-64fbcc5435cc/content, last accessed October 4, 2023.
4. Naphade, M., S. Wang, D. C. Anastasiu, Z. Tang, M-C Chang, Y. Yao, L. Zheng, et al. 2023. "The 7th AI City Challenge." Presented at the *2023 IEEE/CVF Computer Vision and Pattern Recognition Conference*. Vancouver, BC: IEEE. https://openaccess.thecvf.com/content/CVPR2023W/AICity/papers/Naphade_The_7th_AI_City_Challenge_CVPRW_2023_paper.pdf, last accessed October 4, 2023.
5. Naphade, M., S. Wang, D. C. Anastasiu, Z. Tang, M-C Chang, Y. Yao, L. Zheng, et al. 2022. "The 6th AI City Challenge." Presented at the 2022 IEEE/CVF Computer Vision and Pattern Recognition Conference. New Orleans, LA: IEEE. https://openaccess.thecvf.com/content/CVPR2022W/AICity/papers/Naphade_The_6th_AI_City_Challenge_CVPRW_2022_paper.pdf, last accessed October 4, 2023.
6. Rahman, M. S., A. Venkatachalapathy, A. Sharma, J. Wang, S. V. Gursoy, D. Anastasiu, and S. Wang. 2023. "Synthetic Distracted Driving (SynDD1) Dataset for Analyzing Distracted Behaviors and Various Gaze Zones of a Driver." *Data in Brief* 46: 108793. https://www.sciencedirect.com/science/article/pii/S2352340922009969, last accessed October 4, 2023.
7. Rahman, M. S., A. Venkatachalapathy, and A. Sharma. 2022. *Synthetic Distracted Driving (SynDD1) Dataset*. Version 2. Mendeley Data. https://data.mendeley.com/datasets/ptcp7rp3wb/4, last accessed October 4, 2023.
8. Venkatachalapathy, A., M. S. Rahman, A. Raj, J. Merickel, A. Sharma, J. Wang, and S. Velipasalar. 2023. "Deep InSight: A Cloud Based Big Data Analytics Platform for Naturalistic Driving Studies." Accepted for publication in *International Journal of Automotive Engineering*.

SUBMITTED FOR PUBLICATION

1. Chai, W., J. Wang, J. Chen, S. Velipasalar, and A. Sharma "Rethinking the Evaluation of Driver Behavior Analysis Approaches." Submitted to *IEEE Transactions on Intelligent Transportation Systems*.
2. Hasan, M. Z., J. Chen, J. Wang, A. Joshi, S. Velipasalar, C. Hegde, A. Sharma, and S. Srakar. "Vision-Language Models Can Identify Distracted Driver Behavior From Naturalistic Videos." Submitted to *IEEE Transactions on Intelligent Transportation Systems*.

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 the Research Standards and Technical Assessment Support study enabled benchmarking progress and technical assessment of EAR Program-sponsored research teams.[3]

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Karnowski, T. P., D. Aykac, R. Ferrell, L. Thompson, and L. Torkelson. 2022. *Database to Enable Facial Analysis for Driving Studies (DEFADS)*. Report No. ORNL/TM-2022/2786. Oak Ridge, TN: Oak Ridge National Laboratory. https://www.osti.gov/biblio/1901618/, last accessed October 5, 2023.
2. Rachow, M., T. Karnowski, and A. J. O'Toole. 2023. "Identity Masking Effectiveness and Gesture Recognition: Effects of Eye Enhancement in Seeing Through the Mask." https://doi.org/10.48550/arXiv.2301.08408, last accessed October 5, 2023.

VIDEO ANALYTICS FOR AUTOMATIC ANNOTATION OF DRIVER BEHAVIOR AND DRIVING SITUATIONS IN NATURALISTIC DRIVING DATA

VIRGINIA TECH TRANSPORTATION INSTITUTE

In this study, researchers at the Virginia Tech Transportation Institute worked on developing computer vision methods that would facilitate the automatic generation of annotations from the Second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) database using the continuous videos.[2,4] The study aimed to make it easier for researchers to create smaller subsets of data from the more than 1 million h of video data that make up the SHRP2 NDS database. The research team developed and evaluated a series of deep neural network models (including convolutional neural network and recurrent neural network) to capture the spatial and temporal information embedded in the video. Enhanced access to very large datasets with appropriate video annotations will facilitate a quantum leap forward in transportation safety research. Such work could make it possible to explore questions that are currently out of reach of investigators, including the interactions between human drivers and other road users, road infrastructure elements, and roadside objects.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Bhagat, H., S. Jain, L. Abbott, A. Sonth, and A. Sarkar. 2023. "Driver Gaze Fixation and Pattern Analysis in Safety Critical Events." In *2023 IEEE Intelligent Vehicles Symposium IV*. Piscataway, NJ: IEEE. https://ieeexplore.ieee.org/document/10186718, last accessed October 5, 2023.
2. Bhat, S., L. Abbott, and V. Sundharam. 2023. "Deep Intersection and Driving Environment Detection and Its Potential in Driver Safety." Poster presented at the *102nd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.
3. Sonth, A., A. Sarkar, H. Bhagat, and L. Abbott. 2023. "Explainable Driver Activity Recognition Using Video Transformer in Highly Automated Vehicle." In *2023 IEEE Intelligent Vehicles Symposium IV*. Piscataway, NJ: IEEE. https://ieeexplore.ieee.org/document/10186584, last accessed October 5, 2023.

CONFERENCE PRESENTATIONS

1. Sarkar, A. 2023. "Driver Gaze Fixation and Pattern Analysis in Safety Critical Events." Presented at the *10th International Workshop on Naturalistic Driving Data Analytics (NDDA), IEEE Intelligent Vehicles Symposium IV*. Anchorage, AK: IEEE.

Supplementary Materials

Fly ash, a supplementary cementitious material (SCM), is an important constituent in the production of concrete. Although demand for SCMs is increasing, the amount of fly ash produced by coal-fired power plants is decreasing, so the transportation industry is looking for viable alternatives to traditional fly ash that can provide reliable performance.[5] These alternatives, which include nontraditional or off-specification fly ash as well as other SCM sources, are promising because of their abundance and potential economic value. Three projects supported through the EAR Program seek to study and document how the chemical and physical properties of these alternative materials affect the performance of concrete.[6] These projects aim to provide State departments of transportation with information that describes how these materials affect the durability, sustainability, and strength of concrete to help engineers make informed and timely decisions regarding material specifications and concrete mixture performance criteria.

PHYSICALLY INFORMED DATA-DRIVEN METHODS FOR GREATLY ENHANCING THE USE OF HETEROGENEOUS CEMENTITIOUS MATERIALS IN TRANSPORTATION INFRASTRUCTURE

UNIVERSITY OF CALIFORNIA, LOS ANGELES

Researchers at the University of California, Los Angeles, sought to develop what they called "new data-guided pathways" to help determine which grades of fly ashes, including reclaimed and off-spec fly ashes, can be used in the production of concrete for highway construction applications. The project aimed to decipher, through a data-guided and machine-learning approach, how the physical and chemical features of fly ashes—the "genome" of the fly ash—control their performance in concrete.

ACCEPTED FOR PUBLICATION

1. Collin, M., Y. Song, D. P. Prentice, A. R. A. Arnold, K. Ellison, D. A. Simonetti, M. Bauchy, and G. N. Sant. 2023. "Fly Ash Degree of Reaction in Hypersaline NaCl and CaCl2 Brines: Effects of Calcium-Based Additives." *Waste Management* 170: 103–111. https://doi.org/10.1016/j.wasman.2023.08.002, last accessed October 5, 2023.
2. Han, T., S. A. Ponduru, A. Reka, J. Huang, G. Sant, and A. Kumar. 2023. "Predicting Dissolution Kinetics of Tricalcium Silicate Using Deep Learning and Analytical Models." *Algorithms* 16, no. 1: 7. https://doi.org/10.3390/a16010007, last accessed October 5, 2023.
3. Han, T., R. Bhat, S. A. Ponduru, A. Sarkar, J. Huang, G. Sant, H. Ma, N. Neithalath, and A. Kumar. 2023. "Deep Learning to Predict the Hydration and Performance of Fly Ash-Containing Cementitious Binders." *Cement and Concrete Research* 165: 107093. https://doi.org/10.1016/j.cemconres.2023.107093, last accessed October 5, 2023.

Source: FHWA. A clipboard showing samples of fly ash before and after electrostatic separation to reduce the amount of carbon in fly ash.[7]

4. Ponduru, S. A., T. Han, J. Huang, and A. Kumar. 2023. "Predicting Compressive Strength and Hydration Products of Calcium Aluminate Cement Using Data-Driven Approach." *Materials* 16, no. 2: 654. https://doi.org/10.3390/ma16020654, last accessed October 5, 2023.

NONTRADITIONAL AND NATURAL POZZOLAN-BASED SCMS OR INORGANIC POLYMERS FOR TRANSPORTATION INFRASTRUCTURE

PURDUE UNIVERSITY

Researchers at Purdue University, with assistance from researchers at Penn State University and Clarkson University, are seeking to analyze and conduct further studies on how nontraditional and natural pozzolan SCMs might perform in concrete pavements or other transportation structures.[6] These nontraditional sources—calcinated clays, natural pozzolans, bottom ashes, and fluidized bed combustion ashes—are cost competitive and relatively abundant in different U.S. regions. Laboratory tests can create an understanding of how these resources could be used as viable alternatives to fly ash.

ACCEPTED FOR PUBLICATION

1. Arachchige, R. M., and S. Peethamparan. 2023. "Composition and Chain Length of Alkali-Activated Ground Bottom Ash Gels Using NMR." Presented at the *16th International Congress on the Chemistry of Cement*. Bangkok, Thailand: International Congress on the Chemistry of Cement.
2. Mishra, S., and S. Peethamparan. 2023. "Alkali-Silica Reaction Resistance of Alkali-Activated Calcined Clays Using Accelerated Mortar Bar Test." Presented at the *16th International Congress on the Chemistry of Cement*. Bangkok, Thailand: International Congress on the Chemistry of Cement.
3. Rajabipour, F., and M. Sharbaf. 2023 "Predicting the Alkali Contribution of SCMs to Concrete Pore Solution." *Proceedings of the 1st Interdisciplinary Symposium on Smart & Sustainable Infrastructures (ISSSI 2023), 77th RILEM Annual Week*. Vancouver, Canada: RILEM.
4. Sharbaf, M., and F. Rajabipour. 2023. "A New Soluble Alkali Test to Predict the Alkali Contribution of SCMs to Concrete Pore Solution." Presented at the *16th International Congress on the Chemistry of Cement (ICCC 2023)*. Bangkok, Thailand: International Congress on the Chemistry of Cement.
5. Tokpatayeva, R., A. Castillo, J. Yoon, G. Kaladharan, K. Jafari, R. Arachchige, F. Rajabipour, S. Peethamparan, and J. Olek. 2022. "Comparative Study of the Reactivity and Performance of Different Nontraditional and Natural Pozzolans in Cementitious System." *Advances in Civil Engineering Materials* 11, no. 2: 670–693. https://doi.org/10.1520/ACEM20220021, last accessed October 20, 2023.
6. Yoon, J., K. Jafari, R. Tokpatayeva, S. Peethamparan, J. Olek, and F. Rajabipour. 2022. "Characterization and Quantification of the Pozzolanic Reactivity of Natural and Non-Conventional Pozzolans." *Cement and Concrete Composites* 133: 104708. https://doi.org/10.1016/j.cemconcomp.2022.104708, last accessed October 20, 2023.

SUBMITTED FOR PUBLICATION AND PRESENTATIONS

1. Arachchige, R. M., S. Peethamparan, J. Olek, and F. Rajabipour. 2023. "Nontraditional Alumino-Silicate Based Alkali-Activated Mortars - Statistical Optimization of Solution Parameters and Processing Conditions for Optimal Strength, Workability and Setting Time." Submitted and under revision, *Construction and Building Materials*.
2. Arachchige, R. M., S. Peethamparan, J. Olek, and F. Rajabipour. 2023. "Phase Identification and Micromechanical Properties of Nontraditional and Natural Pozzolan based Alkali-Activated Materials." Submitted and under review, *Cement and Concrete Composites*.
3. Castillo, A., R. Tokpatayeva, J. Olek, F. Rajabipour, and S. Peethamparan. 2023. "Influence of Physicochemical Properties of Nontraditional and Natural Pozzolans (NNPs) on Selected Characteristics of Concrete." Accepted for presentation, *Transportation Research Board Annual Meeting*.
4. Mishra, S., and S. Peethamparan. 2023. "ASR Resistance of Ground Bottom Ash-Based Alkali-activated Concrete and the Prospect of Using MCPT for the Evaluation.'' Submitted to *International Conference on Alkali-Aggregate Reaction in Concrete*.

PERFORMANCE-BASED CLASSIFICATION METHODS FOR RECLAIMED FLY ASH

OKLAHOMA STATE UNIVERSITY

Researchers are studying older fly ash from landfills and surface impoundments, called "reclaimed" fly ash, to determine if they provide viable alternatives to the approved fly ash sources currently in use. The researchers seek to combine advanced material characterization methods, performance-based testing, mechanistic modeling, and machine learning to create engineering tools to classify reclaimed fly ash.[6] The project involves tweaking existing testing methods to analyze reclaimed fly ash performance when used for concrete production. The researchers want to capture the differences in chemical composition among the various reclaimed fly ashes and how those differences relate to their performance in concrete. The team also expects to analyze the test data with machine-learning methodology to see what patterns emerge.

ACCEPTED FOR PUBLICATION

1. Kang, S., B. Boyd, and M. T. Ley. 2022. "Performance and Prediction of Non-Traditional Coal-Ash in Concrete with the Particle Model." *Construction and Building Materials* 345: 128170. https://doi.org/10.1016/j.conbuildmat.2022.128170, last accessed October 19, 2023.
2. Kang, S., L. Emerson, J. Lee, and M. T. Ley. 2023. "Determining the Air-Entraining Admixture Dosage in Concrete with Non-Traditional Coal Ash." *Materials and Structures* 56, no. 9. https://doi.org/10.1617/s11527-022-02098-1, last accessed October 19, 2023.

DEVELOPMENT OF AGING RESISTANT BINDER TECHNOLOGY

AUBURN UNIVERSITY

Researchers at Auburn University, along with partnering groups, examined fundamental aspects of asphalt modification to help the highway industry make better choices about pavement systems. In a 3-yr study, the researchers examined six additives to see how they perform as a basis to develop a standard process that can be used to evaluate future anti-aging asphalt additives. By testing the effectiveness of additive products, the researchers aimed to create asphalt mixtures that result in durable and longer lasting roads and pavements. The researchers also examined whether mitigating oxidation through use of certain additives is a viable approach in ensuring the durability of the chemical binders used in asphalt production.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Garita-Jimenez, J., N. Tran, F. Keuliyan, R. Moraes, C. Rodezno, and F. Yin. 2023. "Evaluating Aging Resistant Technologies for Enhancing Cracking Resistance of Asphalt Mixtures." Accepted for publication *Transportation Research Record: Journal of the Transportation Research Board*.
2. Keuliyan, F., R. Moraes, N. Tran, R. West, F. Yin, C. Rodezno, and F. Leiva. 2023. "Evaluation of Innovative Aging-Resistant Technologies to Improve the Cracking Susceptibility of Asphalt Binders." Presented at the *102nd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.
3. Keuliyan, F., R. Moraes, and N. Tran. 2022. "Rheological and Chemical Evaluation of Aging Resistant Binder Technologies." Presented at the *AAPT Annual Meeting*. San Antonio, TX: Association of Asphalt Paving Technologists.
4. Keuliyan, F., R. Moraes, N. Tran, F. Yin, C. Rodezno, and F. Leiva. 2022. "Rheological and Chemical Evaluation of Aging Resistant Binder Technologies." Presented at the *59th Petersen Asphalt Research Conference*. Laramie, WY: Western Research Institute.

Artificial Intelligence

COOPERATIVE PERCEPTION AND CONTROL FOR FREEWAY TRAFFIC SYSTEM OPERATIONS

UNIVERSITY OF CINCINNATI AND THE UNIVERSITY OF CALIFORNIA, LOS ANGELES

The research team aims to develop next-generation Traffic System Management and Operations solutions for freeway systems based on cooperative driving automation. The proposed solution involves cooperative perception (i.e., estimation and prediction using various data sources based on machine-learning and filtering methods) and cooperative control (i.e., advanced artificial intelligence algorithms customized for vehicle- and infrastructure-level control, such as cooperative merging, platooning, and speed harmonization). The work is focusing on computational applications that could substantially increase freeway system safety and mobility to meet the following objectives:

- Integrate traditional and nontraditional highway data to better explain and predict system performance.
- Provide decision support to assist experts in highway system design, operations, and management.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Meng, Z., X. Xia, R. Xu, W. Liu, and J. Ma. 2023. "HYDRO-3D: Hybrid Object Detection and Tracking for Cooperative Perception Using 3D LiDAR." *IEEE Transactions on Intelligent Vehicles* 8, no. 8: 4069–4080. https://ieeexplore.ieee.org/abstract/document/10148929, last accessed October 10, 2023.
2. Xia, X., R. Xu, and J. Ma. 2023. "Secure Cooperative Localization for Connected Automated Vehicles Based on Consensus." *IEEE Sensors Journal* 2023.
3. Xiang, H., R. Xu, X. Xia, Z. Zheng, B. Zhou, and J. Ma. 2023. "V2XP-ASG: Generating Adversarial Scenes for Vehicle-to-Everything Perception." Presented at the 2023 *IEEE International Conference on Robotics and Automation*. London, England.
4. Xu, R., W. Chen, H. Xiang, X. Xia, L. Liu, and J. Ma. 2023. "Model-Agnostic Multi-Agent Perception Framework." Presented at the 2023 *IEEE International Conference on Robotics and Automation*. London, England.
5. Xu, R., J. Li, X. Dong, H. Yu, and J. Ma. 2023. "Bridging the Domain Gap for Multi-Agent Perception." Presented at the 2023 *IEEE International Conference on Robotics and Automation*. London, England.

6. Zheng, Z., X. Han, X. Xia, L. Gao, H. Xiang, and J. Ma. 2023. "OpenCDA-ROS: Enabling Seamless Integration of Simulation and Real-World Cooperative Driving Automation." *IEEE Transactions on Intelligent Vehicles* 8, no. 7: 3775–3780. https://ieeexplore.ieee.org/document/10192346, last accessed October 10, 2023.

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

CARNEGIE MELLON UNIVERSITY

Despite decades of research, mitigating traffic congestion due to nonrecurring causes, such as crashes, disabled vehicles, and adverse weather events, remains quite difficult for highway system operations practitioners.[8] This work requires an automated process of accurate, real-time prediction and proactive operational management that currently does not exist. Researchers from Carnegie Mellon University and the University of Washington Seattle, in their project Predictive Real-Time Traffic Management in Large-Scale Networks Using Model-Based Artificial Intelligence, aim to address this issue. The project seeks to fuse prediction strategies, based on artificial intelligence and machine learning guided by transportation network flow models, with operational strategies. The researchers want to predict nonrecurrent traffic conditions in large-scale networks up to 30 min ahead of the earliest time an incident is reported and proactively recommend real-time operational management strategies.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Haocheng, D., H. Wu, P. Huang, and S. Qian. 2023. "Two-Stage Multi-Task Learning Model for Proactive Non-Recurrent Traffic Prediction." Accepted for presentation at the *2024 Transportation Research Board Annual Meeting*. Washington, DC: Transportation Research Board.

2. Zhang, P., and S. Qian. 2023. "Low-Rank Approximation of Path-Based Traffic Network Models." Accepted for presentation at the *2024 Transportation Research Board Annual Meeting*. Washington, DC: Transportation Research Board.

TRAFFIC INCIDENT DETECTION AND ANALYSIS SYSTEM

TUFTS UNIVERSITY

Researchers at Tufts University and the City College of New York are leveraging artificial intelligence (AI) to improve the detection of highway incidents.[9] In this study, researchers are creating a novel framework using AI and image-processing algorithms. The framework aims to exploit the potential of currently installed highway camera infrastructures for incident detection, including spotting wrong-way driving, crashes, hazardous objects in the roadway, and bicyclists or pedestrians in tunnels. One drawback of existing highway incident detection technologies is their scalability. Monitoring and analyzing the overwhelming quantity of camera data without assistive automated methods is challenging. Utilizing AI, models can be trained to enhance images and provide robust detection and classification of traffic incidents, resulting in more cost-effective deployment of incident-response resources. This research project focuses on solving challenges including the following:

- The lack of a robust automatic incident detection system capable of emphasizing key events with minimal false alarms.
- The problems inherent in current learning algorithms, which significantly degrade in performance under adverse weather conditions.
- The unavailability of a dataset with diverse footage of highway incidents to foster the development and validation of AI algorithms.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Badrieva, S., S. Bernabel, and S. Agaian. 2022. "Comprehensive Analysis and Benchmarking of De-Raining Techniques Through a Rain Model Approach." *Multimodal Image Exploitation and Learning 2022* 12100. Bellingham, WA: SPIE. https://doi.org/10.1117/12.2618314, last accessed October 18, 2023.

2. Frants, V., S. Again, and K. Panetta. 2023. "QCNN-H: Single-Image Dehazing Using Quaternion Neural Networks." *IEEE Transactions on Cybernetics* 53, no. 9: 5448–5458. https://doi.org/10.1109/TCYB.2023.3238640, last accessed October 18, 2023.

3. Frants, V., S. Agaian, and K. Panetta. 2023. "QSAM-Net: Rain Streak Removal by Quaternion Neural Network With Self-Attention Module." *IEEE Transactions on Multimedia*. https://doi.org/10.1109/TMM.2023.3271829, last accessed October 18, 2023.

4. Frants, V., and S. Agaian. 2023. "Weather Removal With a Lightweight Quaternion Chebyshev Neural Network." *Multimodal Image Exploitation and Learning 2023* 12526. Bellingham, WA: SPIE. https://doi.org/10.1117/12.2664858, last accessed October 18, 2023.
5. Hovhannisyan, S. A., H. A. Gasparyan, S. S. Agaian, and A. Ghazaryan. 2022. "AED-Net: A Single Image Dehazing." *IEEE Access* 10: 12465–12474. https://doi.org/10.1109/ACCESS.2022.3144402, last accessed October 18, 2023.
6. Kezebou, L., V. Oludare, K. Panetta, J. Intriligator, and S. Agaian. 2022. "Highway Accident Detection and Classification from Live Traffic Surveillance Cameras: A Comprehensive Dataset and Video Action Recognition Benchmarking." *Multimodal Image Exploitation and Learning 2022* 12100. Bellingham, WA: SPIE. https://doi.org/10.1117/12.2618943, last accessed October 18, 2023.
7. Liu, S., and S. S. Agaian. 2023. "ALSA: Adaptive Low-light Correction and Self-Attention Module for Vehicle Re-Identification." *Artificial Intelligence Evolution* 4, no. 2: 99–119. https://doi.org/10.37256/aie.4220232901, last accessed October 18, 2023.

SUBMITTED FOR PUBLICATION OR IN PREPARATION

1. Bernabel, S. A., and S. S. Agaian. "NDELS: Nighttime Dehazing Low-Light Enhancement and Light Suppression."
2. Frants V., S. Agaian, K. Panetta, and P. Huang. "CMAWRNet: Multiple Adverse Weather Removal via a Unified Quaternion Neural Architecture." Submitted to *IEEE Intelligent Transportation Systems Transactions*.
3. Frants, V., S. Agaian, K. Panetta, and J. Intriligator. "DCQ-Net: A Deep Quaternion Neural Network for Accident Detection in Real-Life Scenarios."
4. Kaplan, L. E., V. Frants, and S. Agaian. "CUNY Video Database for Collision and Anomaly Detection in Real-Life Traffic Scenarios."
5. Liu, S., and S. S. Agaian. "VERI-D: A New Dataset and Method for Multi-Camera Vehicle Re-Identification of Damaged Cars." Submitting to *APL Machine Learning*.

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

MICHIGAN TECHNOLOGICAL UNIVERSITY

Researchers at the Michigan Technological University are investigating the potential to shift winter maintenance decisionmaking from a model-driven to an artificial intelligence (AI)-enhanced framework.[10] The researchers are developing 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 decisionmaking. The team is investigating opportunities from AI to analyze real-world situations in realtime. Recurrent neural networks (RNNs) and road condition predictions provide a data-driven environment. Deep reinforced learning takes the RNN predictions and puts them into action using machine learning to make autonomous decisions. Convolutional neural networks provide real-time road condition sensing. To test these machine-learning models in the field, researchers are working with the Michigan DOT and Michigan county road agencies to conduct field tests. The researchers are developing a closed-loop approach consisting of data gathering, condition predictions, decisionmaking, validation, and human intervention. This approach maximizes AI's capability to significantly improve winter maintenance operations, safety, and mobility; reduce labor hours and costs; and indirectly enhance pavement design and management.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

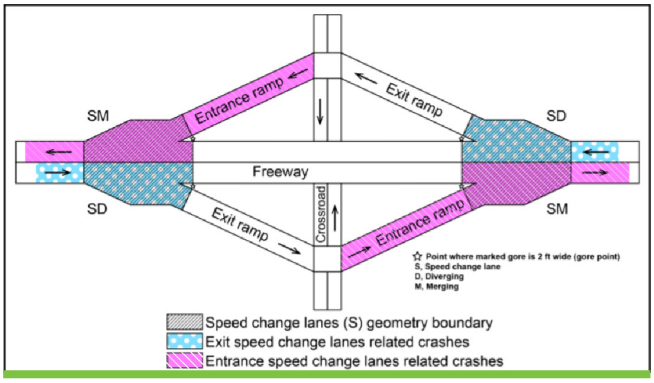
1. Tavakoli Dastjerdi, M. H., Z. Liu, B. Azmoon, and X. Yuan. 2023. "Enhancing Winter Road Maintenance via Cloud Computing." *IEEE Internet Computing* 27, no. 4: 6–14. https://ieeexplore.ieee.org/abstract/document/10098262, last accessed November 17, 2023.

Realistic Artificial Data (RAD)

MIMIC: MULTIDISCIPLINARY INITIATIVE ON METHODS TO INTEGRATE AND CREATE ARTIFICIAL REALISTIC DATA

UNIVERSITY OF MISSOURI

To expand traditional safety modeling practices and results, this project developed a framework that would generate RADs that mimic the known causal relationships between contributing factors and crashes. The researchers applied the framework to generate RADs for ramp terminals and speed change lane facilities at diamond interchanges.[11] The researchers also developed Web-based software to provide easy access to the RADs by other researchers who wanted to test their models.



© 2016 Missouri DOT. Modifications by FHWA to show the gore point, speed change, diverging, and merging lanes. Components of speed change lanes at an intersection.[11]

The researchers also used RADs to evaluate new behavioral and roadway countermeasures by generating virtual reality simulation testbeds for crashes and near-crashes occurring at interchanges. A graphical user interface developed by the researchers facilitated the testbeds for left-turn and speed change lane crashes. Virtual reality provides an engaging platform for evaluating countermeasures and educating the public about interchange crashes, which can help achieve the U.S. Department of Transportation's goal of zero roadway fatalities.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

Li, C., P. Edara, and Y. Shang. 2023. "Crash Frequency Modeling Using Realistic Artificial Data." 2023 *IEEE Conference on Artificial Intelligence (CAI)*. Piscataway, NJ: IEEE, 28–29. https://ieeexplore.ieee.org/abstract/document/10195079, last accessed October 10, 2023.

DEVELOPMENT AND APPLICATION OF A DISAGGREGATE ARTIFICIAL REALISTIC DATA GENERATOR FOR COMPUTATIONALLY TESTING SAFETY ANALYSIS METHODS

UNIVERSITY OF CONNECTICUT

In a collaboration between the University of Connecticut and the University of Central Florida, researchers are building a RAD tool for generating datasets for all facility types using different input combinations.[12] The tool will be customizable and capable of generating datasets at both the macroscopic and microscopic levels. The macroscopic level is suited for single-step data models, such as those currently used in transportation safety analysis. The microscopic level can compare advanced research models and consider complex factors like human behavior as well as accommodate major changes in transportation, such as the inclusion of autonomous vehicles on roadways.

To show proof of concept, the research team will generate two case studies: one focused on vehicle crashes on segments and one focused on vehicle and pedestrian crashes at intersections. Developing RAD tools is key to the Federal Highway Administration (FHWA) goal of expanding the adoption of data-driven safety analysis, as it will enable users to objectively select the best methods for their data.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Hoover, L, M. I. Jahan, T. Bhowmik, S. D. Tirtha, K. C. Konduri, J. Ivan, K. Wang, S. Zhao, J. Auld, and N. Eluru. 2023. "Implementation of a Realistic Artificial Data Generator for Crash Data Generation." Submitted and in review with *Accident Analysis and Prevention*.
2. Olufowobi, O., J. Ivan, S. Zhao, and K. Wang. 2023. "Application of Realistic Artificial Data for Testing Various Crash Safety Analysis: A Case Study for Rural Two-Lane Undivided Highways." Presented at the *102nd Transportation Research Board Annual Meeting*. Washington, DC: Transportation Research Board.
3. Olufowobi, O., J. Ivan, S. Zhao, and K. Wang. 2023. "Application of Realistic Artificial Data for Testing Artificial Data for Testing Various Crash Safety Analysis: A Case Study for Rural Two-Lane Undivided Highways." *Transportation Research Record*. https://doi.org/10.1177/03611981231175901, last accessed October 13, 2023.

Blockchain

DECENTRALIZED VEHICLE CREDENTIAL MANAGEMENT SYSTEM BASED ON CONSORTIUM BLOCKCHAIN

NEW JERSEY INSTITUTE OF TECHNOLOGY

Vehicle-to-vehicle (V2V) communication uses wireless technology to send and receive messages with surrounding vehicles.[13] V2V communication increases highway safety through precollision warnings and provides convenience, such as information on traffic congestion. It is becoming standard in the automotive trade to install equipment in new vehicles that allow V2V communication. One concern in wireless communication is the increasing potential for unauthorized intrusions or cyberattacks and the breech of personal privacy. This project is researching and developing software that increases V2V security by improving upon the current "handshake" protocols for authenticating vehicle identification and maintaining security during message transportation.

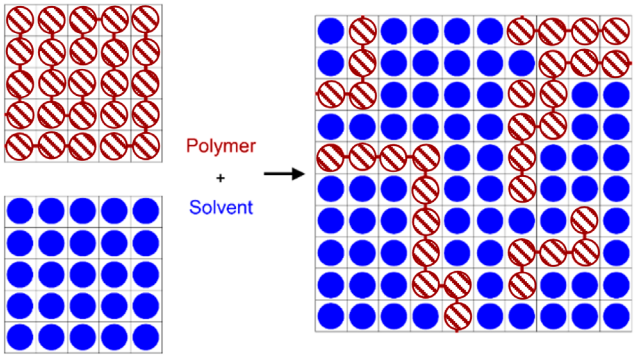
ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Du, W., A. Dash, J. Li, H. Wei, and G. Wang. 2023. "Safety in Traffic Management Systems: A Comprehensive Survey." *Designs* 7 no. 4: 100. https://doi.org/10.3390/designs7040100, last accessed October 29, 2023.
2. Du, W., J. Ye, J. Gu, J. Li, H. Wei, and G. Wang. 2023. "SafeLight: A Reinforcement Learning Method toward Collision-free Traffic Signal Control." *AAAI 23: Proceedings of the Third-Seventh AAAI Conference on Innovative Applications of Artificial Intelligence and Thirteenth Symposium on Educational Advances in Artificial Intelligence*. Washington, DC: Association for the Advancement of Artificial Intelligence. 14801–14810. https://doi.org/10.1609/aaai.v37i12.26729, last accessed October 29, 2023.
3. He, S., Y. Lu, Q. Tang, G. Wang, and C. Wu. 2022. "Blockchain-Based P2P Content Delivery With Monetary Incentivization and Fairness Guarantee." *IEEE Transactions on Parallel and Distributed Systems* 34, no. 2: 746–765. https://ieeexplore.ieee.org/document/9929262, last accessed October 29, 2023.
4. Yao, W., F. P. Deek, R. Murimi, and G. Wang. 2023. "SoK: A Taxonomy for Critical Analysis of Consensus Mechanisms in Consortium Blockchain." *IEEE Access* 11: 79572–79587. https://ieeexplore.ieee.org/document/10192902, last accessed October 29, 2023.
5. Yao, W., J. Gu, W. Du, F. P. Deek, and G. Wang. 2022. "A Novel Anomaly Detection and Privacy-Preserving Framework Using Blockchain and Neural Networks in Tokenomics." *International Journal of Artificial Intelligence & Applications* 13, no. 6. https://aircconline.com/ijaia/V13N6/13622ijaia02.pdf, last accessed October 29, 2023.
6. Yao, W., Y. Liu, F. P. Deek, and G. Wang. 2023. "iBCTrans: A Practical Blockchain-Based Framework for Cellular Vehicular-To-Everything Networks." Accepted for publication in *IEEE Blockchain*.
7. Yao, W., Y. Liu, F. P. Deek, and G. Wang. 2023. "VDKMS: Vehicular Decentralized Key Management System for Cellular Vehicular-to-Everything Networks, A Blockchain-Based Approach." Accepted for publication in *IEEE Global Communications Conference*.

Waste Plastics In Asphalt Binder

IMPROVING THE COMPATIBILITY OF WASTE PLASTIC AND ASPHALT BINDER VIA THEORETICALLY JUSTIFIED IDENTIFICATION OF COMPATIBLE BLENDS

LOUISIANA TECH UNIVERSITY



© 2021 Louisiana Tech University. This figure shows the model used to calculate the compatibility of different polymers and asphalt (the "solvent" in the figure).[14]

Waste plastic, though largely considered an environmental concern, has the potential to be a valuable resource.[14] Use of waste plastics to supplement traditional asphalt binders can reduce resource consumption and become an alternative to the disposal of waste plastic in landfills. However, challenges exist with using waste plastics in asphalt. Knowledge of waste plastic's compatibility with asphalt binders is limited, as are the different types of polymers that make up waste plastic. The researchers for this 3-yr, first-of-its-kind project are investigating and developing a computational model that can understand on a molecular and atomic level which waste polymers are compatible with which given asphalt binders to optimize the blend's performance. Through this computational model, the researchers aim to provide a foundation for using waste plastic in asphalt pavements on an industrial scale.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Chowdhury, A., P. Nourian, N. M. Wasiuddin, and A. Peters. 2023. "Investigation of Phase Separation Behavior of Polymer-Asphalt Mix Using Molecular Dynamics Simulation." Under review in *Fuel*.

2. Chowdhury, A., P. Nourian, N. M. Wasiuddin, and A. Peters. 2023. "MD Simulation of Waste Plastic-Asphalt Compatibility." Presented at the 2023 *AIChE Annual Meeting*. Orlando, FL: AIChE.
3. Islam, M. R., and N. M. Wasiuddin. 2022. "Identification of Low Density Polyethylene, High Density Polyethylene, and Polypropylene in Asphalt Binder with a Hand-Held FTIR Spectrometer." Proceedings of the *2022 Tran-SET Conference*. Austin, TX: Transportation Consortium of South-Central States. https://ascelibrary.org/doi/10.1061/9780784484609.002, last accessed November 2, 2023.
4. Peters, A., and N. M. Wasiuddin. 2023. "A Coarse-Grained Model for Asphalt Binder and Polymer Mixtures Based on the MARTINI Forcefield." To be presented at the *103rd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.
5. Rahman, S. M. R., R. Hossain, N. M. Wasiuddin, and A. Peters. 2022. "Understanding Phase Separation, Aging Characteristics, and SARA Fractions of HDPE, LDPE, and PP Modified Asphalt Binder." Presented at *101st Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.
6. Selim, S., M. R. Islam, N. M. Wasiuddin, A. Peters. 2023. "A Thermodynamic Approach to Investigate Compatibility of HDPE, LDPE, and PP Modified Asphalt Binders Using a Novel Differential Scanning Calorimeter (DSC) Method." To be presented at the *103rd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.

Interagency Research

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

AUGMENTED REALITY FOR CONTROL OF RESERVATION-BASED INTERSECTIONS WITH MIXED AUTONOMOUS NON-AUTONOMOUS FLOWS

UNIVERSITY OF TEXAS AUSTIN AND UNIVERSITY OF WASHINGTON

If there were only fully automated vehicles, an intersection could, in theory, greatly reduce wait times and traffic congestion.(15) Yet even one manually driven vehicle can significantly reduce these benefits. Legacy vehicles will be on the road for years to come, so researchers at the University of Texas at Austin are examining how to accommodate both fully automated and manually driven vehicles on the road. The researchers will use an intersection control system to transmit a time reservation to fully automated vehicles and use augmented reality and a heads-up display, such as a projection on the windshield, to notify the human drivers to either speed up or slow down to drive through the intersection at their appointed time. This smart intersection concept would also incorporate nonmotorized travelers, who would be connected through augmented-reality goggles or their smartphones. These devices would then communicate to the pedestrian or the bicyclist when to cross. The researchers developed algorithms based on human behavior that help vehicles and humans safely and efficiently pass through an intersection. Then, the researchers experimented with these algorithms using human participants outfitted with augmented-reality devices in vehicles and on their person. (NSF award 17-39964)

ACCEPTED FOR PUBLICATION

1. Du, B., K. Qian, C. Claudel, and D. Sun. 2022. "Jacobi-Style Iteration for Distributed Submodular Maximization." *IEEE Transactions on Automatic Control* 67, no. 9. https://ieeexplore.ieee.org/document/9789722, last accessed October 16, 2023.
2. Mohamed, A., and F. Lejarza. 2022. "HAR-GCNN: Deep Graph CNNs for Human Activity Recognition From Highly Unlabeled Mobile Sensor Data." 2022 *IEEE International Conference on Pervasive Computing and Communications* Workshops and other Affiliated Events (PerCom Workshops). Alexandria, VA: National Science Foundation. https://par.nsf.gov/biblio/10386595, last accessed October 16, 2023.
3. Mohamed, A., and D. Zhu. 2022. "Social-Implicit: Rethinking Trajectory Prediction Evaluation and The Effectiveness of Implicit Maximum Likelihood Estimation." Presented at the *European Conference on Computer Vision*. Tel Aviv, Israel: European Computer Vision Association.

IDENTIFYING, CHARACTERIZING, AND SHAPING MULTI-SCALE CYBER-HUMAN INTERACTIONS IN MIXED AUTONOMOUS/CONVENTIONAL VEHICLE TRAFFIC

UNIVERSITY OF WISCONSIN-MADISON

Researchers at the University of Wisconsin-Madison are exploring what makes human drivers lose trust in vehicle automation, leading the driver to intervene unnecessarily.(15) The researchers are exploring scenarios that include 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 are using a driving simulator and software to simulate traffic, providing the capability to test automated vehicle algorithms and human-driven vehicle simulations safely and efficiently. For the next phase of this project, the researchers are designing experiments to include human participants in controlled field tests. (NSF award 17-39869)

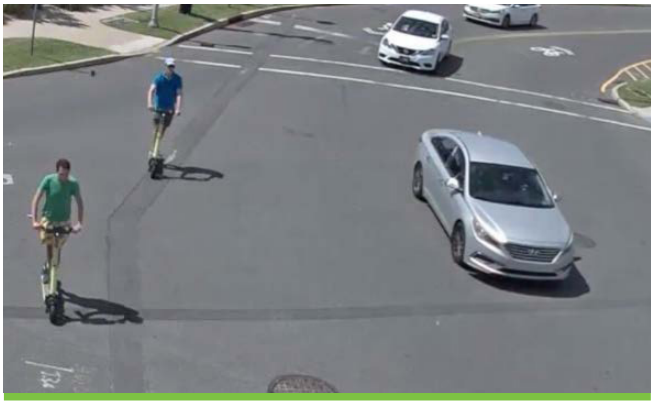
ACCEPTED FOR PUBLICATION

1. Elmquist, A., R. Serban, and D. Negrut. 2023. "Synthetic Image Generation for Robot Simulation: Quantifying the Impact of Model Modifications on Perception." *IEEE Sensors Journal* 23, no. 16: 18304–18315. https://ieeexplore.ieee.org/document/10163921, last accessed October 16, 2023.
2. Elmquist, A., R. Serban, and D. Negrut. 2022. "A Performance Contextualization Approach to Validating Camera Models for Robot Simulation." https://arxiv.org/abs/2208.01022, last accessed October 16, 2023.
3. Kamaraj, A. V., J. Lee, J. E. Domeyer, S. Y. Liu, and J. D. Lee. 2023. "Comparing Subjective Similarity of Automated Driving Styles to Objective Distance-Based Similarity." *Human Factors*. https://journals.sagepub.com/doi/10.1177/00187208221142126, last accessed October 16, 2023.
4. Kamaraj, A. V., J. Lee, J. Parker, J. E. Domeyer, S. Y. Liu, and J. D. Lee. 2023. "Bimodal Trust: High and Low Trust in Vehicle Automation Influence Response to Automation Errors." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 67.
5. Unjhawala, H. M., R. Zhang, W. Hu, J. Wu, R. Serban, and D. Negrut. 2023. "Using a Bayesian-Inference Approach to Calibrating Models for Simulation in Robotics." *Journal of Computational and Nonlinear Dynamics* 18, no. 6: 061004. https://asmedigitalcollection.asme.org/computationalnonlinear/article-abstract/18/6/061004/1160342/Using-a-Bayesian-Inference-Approach-to-Calibrating?redirectedFrom=fulltext, last accessed October 16, 2023.
6. Zhou, Y., X. Zhong, Q. Chen, S. Ahn, J. Jiang, and G. Jafarsalehi. 2023. "Data Driven Analysis for Disturbance Amplification in Car-Following Behavior of Automated Vehicles." *Transportation Research Part B* 174: 102768. https://doi.org/10.1016/j.trb.2023.05.005, last accessed October 16, 2023.
7. Zhou, Z. 2023. "An Open-Source Chrono-Based Framework for Large-Scale Traffic Simulation With Human-in-the-Loop." Master thesis. University of Wisconsin-Madison. http://dx.doi.org/10.13140/RG.2.2.36555.36643, last accessed October 16, 2023.
8. Zhou, Z., H. Unjhawala, A. V. Kamaraj, A. Kissel, J. D Lee, R. Serban, and D. Negrut, 2023. "A Chrono-Based Framework for Large-Scale Traffic Simulation with Human-In-The-Loop." Proceedings of the *Multibody 2023 11th ECCOMAS Thematic Conference on Multibody Dynamics*. Lisbon, Portugal: IDMEC. https://doi.org/10.13140/RG.2.2.23133.59361, last accessed October 16, 2023.

MAKING MICROMOBILITY SMARTER AND SAFER

RUTGERS UNIVERSITY

The growth of micromobility vehicles (transportation devices such as pedal-driven and electric-assist bicycles as well as 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]



© 2021 Rutgers University. E-scooters being used alongside car traffic.[16]

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. The Rutgers University research team seeks to gather better data and create technological tools that help improve safety for pedestrians and micromobility vehicle users. (NSF award 19-51890)

ACCEPTED FOR PUBLICATION

1. Fang, Z., G. Wang, Y. Yang, F. Zhang, Y. Wang, and D. Zhang. 2022. "A Long-Term Travel Delay Measurement Study Based on Multi-Modal Human Mobility Data." *Scientific Reports* 12. https://doi.org/10.1038/s41598-022-19394-z, last accessed October 16, 2023.

2. Tan, H., Y. Yuan, S. Zhong, and Y. Yang. 2023. "Joint Rebalancing and Charging for Shared Electric Micromobility Vehicles with Human-System Interaction." *Proceedings of the ACM/IEEE 14th International Conference on Cyber-Physical Systems*. New York, NY: Association for Computing Machinery. 235–236. https://doi.org/10.1145/3576841.3589613, last accessed October 16, 2023.

3. Wang, G., F. Zhang, and D. Zhang. 2023. "When Mobility on Demand Meets Vehicle Electrification: A Longitudinal Study on Evolution of City-Scale Ridesharing." *CCF Transactions on Pervasive Computing and Interaction* 5: 226–240. https://doi.org/10.1007/s42486-023-00125-w, last accessed October 16, 2023.

4. Wen, S., H. Wang, and D. Metaxas. 2022. "Social ODE: Multi-Agent Trajectory Forecasting with Neural Ordinary Differential Equations." *Computer Vision—ECCV 2022. ECCV 2022*. Lecture Notes in Computer Science 13682. https://par.nsf.gov/biblio/10431064, last accessed October 16, 2023.

5. Xie, X., Z. Hong, Z. Qin, Z. Fang, Y. Tian, and D. Zhang. 2022. "TransRisk: Mobility Privacy Risk Prediction Based on Transferred Knowledge." *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 6, no. 2: 1–19. https://doi.org/10.1145/3534581, last accessed October 16, 2023.

6. Zhong, S., W. Lyu, D. Zhang, and Y. Yang. 2022. "BikeCAP: Deep Spatial-Temporal Capsule Network for Multi-Step Bike Demand Prediction." *2022 IEEE 42nd International Conference on Distributed Computing Systems (ICDCS)*. New York, NY: IEEE. 831–841. https://doi.org/10.1109/ICDCS54860.2022.00085, last accessed October 16, 2023.

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 3-yr 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 20-38984)

© 2022 Columbia University. The researchers are using cameras to capture traffic data.[19]

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Angus, A., Z. Duan, G. Zussman, and Z. Kostic. 2022. "Real-Time Video Anonymization in Smart City Intersections." *IEEE 19th International Conference on Mobile Ad Hoc and Smart Systems (MASS)*. New York, NY: IEEE. 514–522. https://doi.org/10.1109/MASS56207.2022.00078, last accessed October 16, 2023.

2. Bautista-Montesano, R., R. Galluzzi, Z. Mo, Y. Fu, R. Bustamante-Bello, and X. Di. 2023. "Longitudinal Control Strategy for Connected Electric Vehicle with Regenerative Braking in Eco-Approach and Departure." *Applied Sciences* 13, no. 8: 5089. https://doi.org/10.3390/app13085089, last accessed October 16, 2023.

3. Bautista-Montesano, R., R. Galluzzi, K. Ruan, Y Fu, and X. Di. 2022. "Autonomous Navigation at Unsignalized Intersections: A Coupled Reinforcement Learning and Model Predictive Control Approach." *Transportation Research Part C: Emerging Technologies* 139: 103662. https://doi.org/10.1016/j.trc.2022.103662, last accessed October 16, 2023.

4. Di, X., R. Shi, Z. Mo, and Y. Fu. 2023. "Physics-Informed Deep Learning for Traffic State Estimation: A Survey and the Outlook." *Algorithms* 16, no. 6: 305. https://doi.org/10.3390/a16060305, last accessed October 16, 2023.

5. Du, Q., K. Huang, J. Scott, and W. Shen. 2023. "A Space-Time Nonlocal Traffic Flow Model: Relaxation Representation and Local Limit." *Discrete and Continuous Dynamical Systems* 43, no. 9: 3456–3484. https://doi.org/10.3934/dcds.2023054, last accessed October 16, 2023.

6. Ghasemi, M., and S. Kleisarchaki. 2023. "Real-Time Multi-Camera Analytics for Traffic Information Extraction and Visualization." Presented at *IEEE PerCom '23*. Atlanta, GA: IEEE. https://par.nsf.gov/biblio/10451156, last accessed October 16, 2023.

7. Ghasemi, M., S. Kleisarchaki, T. Calmant, J. Lu, S. Ojha, Z. Kostic, L. Gürgen, G. Zussman, and J. Ghaderi. 2023. "Real-Time Multi-Camera Analytics for Traffic Information Extraction and Visualization." Presented at *IEEE PerCom '23*. Atlanta, GA: IEEE. https://par.nsf.gov/biblio/10406095, last accessed October 16, 2023.

8. Kostic, Z., A. Angus, Z. Yang, Z. Duan, I. Seskar, G. Zussman, and D. Raychaudhuri. 2022. "Smart City Intersections: Intelligence Nodes for Future Metropolises." *Computer* 55, no. 12: 74–85. https://doi.org/10.1109/MC.2022.3206273, last accessed October 16, 2023.

9. Liu, S., Y. Wang, X. Chen, Y. Fu, and X. Di. 2022. "SMART-eFlo: An Integrated SUMO-Gym Framework for Multi-Agent Reinforcement Learning in Electric Fleet Management Problem." *2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC)*. New York, NY: IEEE. https://par.nsf.gov/biblio/10447569, last accessed October 16, 2023.

10. Mo, Z., and X. Di. 2022. "Uncertainty Quantification of Car-following Behaviors: Physics-Informed Generative Adversarial Networks." *The 28th ACM SIGKDD in conjunction with the 11th International Workshop on Urban Computing (UrbComp2022)*. https://par.nsf.gov/biblio/10359038, last accessed October 16, 2023.

11. Mo, Z., and Y. Fu. 2022. "TrafficFlowGAN: Physics-Informed Flow Based Generative Adversarial Network for Uncertainty Quantification." Presented at the *European Conference on Machine Learning and Data Mining (ECML PKDD)*. Torino, Italy. https://par.nsf.gov/biblio/10359039, last accessed October 16, 2023.

12. Mo, Z., W. Li, Y. Fu, K. Ruan, and X. Di. 2022. "CVLight: Decentralized Learning for Adaptive Traffic Signal Control with Connected Vehicles." *Transportation Research Part C: Emerging Technologies* 141: 103728. https://doi.org/10.1016/j.trc.2022.103728, last accessed October 16, 2023.

References

1. FHWA. 2020. *Safer, More Reliable Transportation with Behavioral Economics: Cellphone Use and Managed Lane Choice*. Publication No. FHWA-HRT-20-013. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/20013/20013.pdf, last accessed September 28, 2023.

2. FHWA. 2022. *The Role of Artificial Intelligence and Machine Learning in Federally Supported Surface Transportation: 2022 Updates*. Report No. FHWA-HRT-22-026. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/22026/22026.pdf, last accessed September 28, 2023.

3. FHWA. 2015. *Video Analytics Research Projects*. Report No. FHWA-HRT-15-025. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/15025/index.cfm, last accessed November 21, 2022.

4. Virginia Tech Transportation Institute. 2020. "InSight Data Access Website: SHRP2 Naturalistic Driving Study" (website). https://insight.shrp2nds.us/, last accessed September 28, 2023.

5. Al-Shmaisani, S., and M. Juenger. 2020. "What Does the Changing Face of Electricity Production Mean for Concrete?" *Public Roads* 83, no. 4. https://highways.dot.gov/public-roads/winter-2020/what-does-changing-face-electricity-production#:~:text=Table%20of%20Contents-,What%20Does%20the%20Changing%20Face%20of%20Electricity%20Production%20Mean%20for,industry%20is%20looking%20for%20alternatives, last accessed September 28, 2023.

6. FHWA. 2020. *Supplementary Cementitious Material Advancements: Helping to Make Longer Lasting Highway 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 September 6, 2023.

7. FHWA. 2014. *EAR Program Research Results: Updated through 2014*." Publication No. FHWA-HRT-15-024. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/15024/15024.pdf, last accessed September 6, 2023.

8. FHWA. Forthcoming. *Predictive Real-Time Management in Large-Scale Networks Using Model-Based Artificial Intelligence*. Publication No. FHWA-HRT-23-107. Washington, DC: Federal Highway Administration.

9. FHWA. n.d. "Traffic Incident Detection and Analysis System (TIDAS)" (web page). https://highways.dot.gov/research/projects/traffic-incident-detection-and-analysis-system-tidas, last accessed September 29, 2023.

10. FHWA. 2021. *Implementation of AI Framework 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 September 29, 2023.

11. Edara, P., C. Sun, H. Brown, P. Savolainen, V. Shankar, B. Balakrishnan, Y. Shang, et al. 2023. *Multidisciplinary Initiative to Create and Integrate Realistic Artificial Datasets*. Report No. FHWA-HRT-23-058. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-058.pdf, last accessed October 2, 2023.

12. FHWA. 2020. *Realistic Artificial Datasets: Objective Evaluation of Data-Driven Safety Analysis Models*. Publication No. FHWA-HRT-20-047. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/20047/20047.pdf, last accessed October 2, 2023.

13. FHWA. 2021. *Securing Vehicle-to-Vehicle Communication Through Consortium Blockchain*. Publication No. FHWA-HRT-21-048. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/21048/21048.pdf, last accessed October 2, 2023.

14. FHWA. 2021. *Improving the Compatibility of Waste*. Publication No. FHWA-HRT-21-084. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/21084/21084.pdf, last accessed October 2, 2023.

15. FHWA. 2020. *Preparing Our Nation's Roadways for Advanced Vehicle Technologies*. Publication No. FHWA-HRT-20-049. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/20049/20049.pdf, last accessed October 2, 2023.

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 October 2, 2023.

17. National Association of City Transportation Officials. 2020. *Shared Micromobility in the U.S.: 2019*. New York, NY: National Association of City Transportation Officials. https://nacto.org/shared-micromobility-2019/, last accessed April 18, 2022.

18. North American Bikeshare and Scootershare Association. 2021. *2nd Annual Shared Micromobility State of the Industry Report*. Portland, ME: North American Bikeshare and Scootershare Association. https://share.hsforms.com/19DY9nNTJQemTS57h3SD6CA55271, last accessed May 18, 2022.

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 October 2, 2023.

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 problemsolving. 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.

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.

The program has awarded 101 research projects on 57 different topics between 2007 and 2021. The research awards include work by multidisciplinary teams at 80 academic institutions, 57 private companies, 13 State and local agencies, 10 Federal laboratories, and 10 foreign institutions.

Learn More

For more information, see the EAR Program website at https://highways.dot.gov/research/exploratory-advanced-research. 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

Recommended Citation: Federal Highway Administration, *Exploratory Advanced Research (EAR) Program Compendium of Papers from Funded Research Projects* (Washington, DC: 2023)
https://doi.org/10.21949/1521903

FHWA-HRT-24-020
HRTM-30/12-23(50)E