Exploratory Advanced Research (EAR) Program

Compendium of Papers from Funded Research Projects

Traffic modeling relies on data from highways such as the Lyndon B Johnson Freeway in Dallas, TX.
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Behavioral Economics for Managed Lanes

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. 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 may enable the development of more accurate models for predicting travelers' choices on the road and may 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., M. Burris, A. Brown, V. Vitaku. 2022. "Using Behavioral Economics to Identify Potential Managed Lane Users." *Transportation Research Record* 2676, no. 8: 144–158.

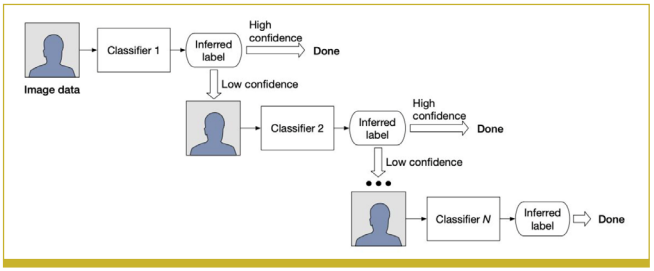

Illustration of the general cascade concept.
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Computer Vision

AUTOMATED VIDEO PROCESSING ALGORITHMS TO DETECT AND CLASSIFY HIGH-LEVEL BEHAVIORS

UNIVERSITY OF MICHIGAN

Researchers for this study developed improved video processing algorithms that can identify more complex behavior and actions of individuals (i.e., pedestrians, drivers, bicyclists) in various traffic situations. The research team wanted to build on existing video-processing algorithms that can identify basic behavior, "primitives" (such as when a subject's hand is near their head), but cannot always identify a "high-level" behavior (such as talking on a cellphone). Specifically, the researchers aimed to:

- Use a bottom-up machine-learning approach to train an algorithm to recognize high-level behaviors using object detection, human-pose estimation, and behavior classification.
- Use a top-down approach to catalog primitive and high-level behaviors and develop a statistical prediction model to link them.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Miao, H., S. Zhang, and C. Flannagan. 2022. "Driver Behavior Extraction From Videos in Naturalistic Driving Datasets with 3D ConvNets." *Journal of Big Data Analytics in Transportation* 4, no. 1: 41–55.
2. Kanu-Asiegbu, A. M., R. Vasudevan, and X. Du. 2021. "Leveraging Trajectory Prediction for Pedestrian Video Anomaly Detection." In *IEEE Symposium Series on Computational Intelligence (SSCI)*, 1–8. Piscataway, NJ: IEEE. DOI: 10.1109/SSCI50451.2021.9660004, last accessed November 4, 2022.

U.S. Department of Transportation
Federal Highway Administration

3. Yao, Y., E. Atkins, M. Johnson-Roberson, R. Vasudevan, and X Du. 2021. "BiTrap: Bi-Directional Pedestrian Trajectory Prediction with Multi-Modal Goal Estimation." *IEEE Robotics and Automation Letters* 6, no. 2: 1463–1470. https://doi.org/10.48550/arXiv.2007.14558, last accessed November 4, 2022.
4. Yao, Y., E. Atkins, M. J. Roberson, R. Vasudevan, and X. Du. 2021. "Coupling Intent and Action for Pedestrian Crossing Behavior Prediction." In *Proceedings of the Thirtieth International Joint Conference on Artificial Intelligence (IJCAI)*. Montreal, ON: IJCAI. 1238–1244. https://doi.org/10.24963/ijcai.2021/171, last accessed November 4, 2022.
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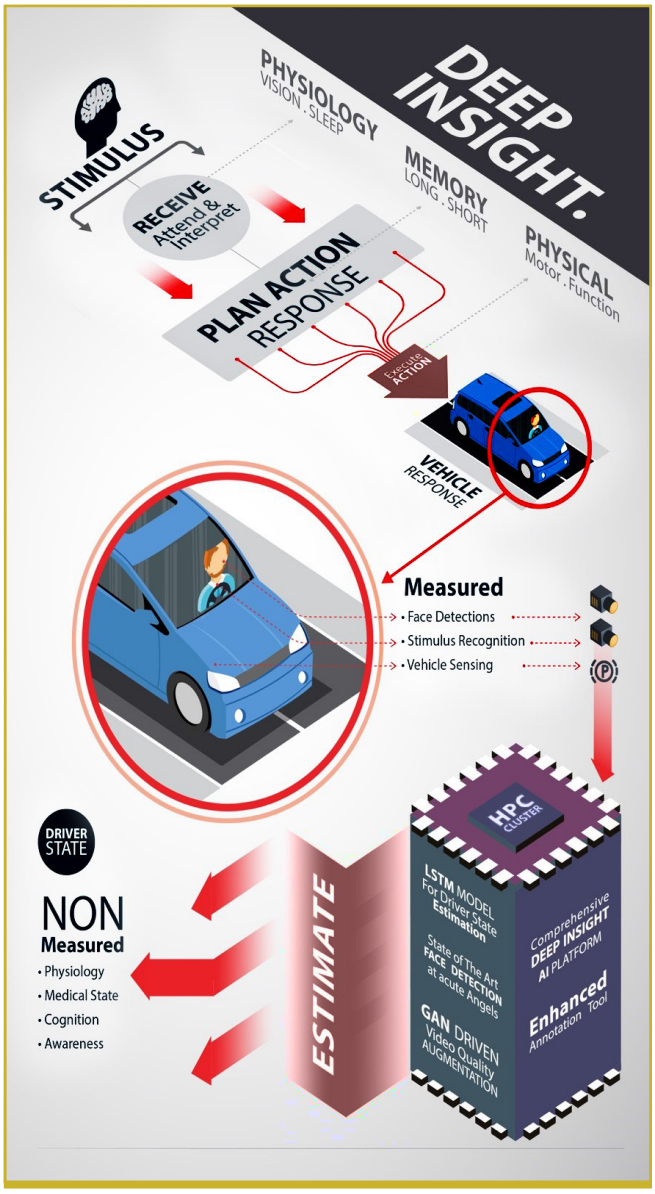
6. He, W., M. R. Anderson, M. Strome, and M. Cafarella. 2020. "A Method for Optimizing Opaque Filter Queries." *In Proceedings of the 2020 ACM SIGMOD International Conference on Management of Data*. New York, NY: Association for Computing Machinery. 1257–1272. https://dl.acm.org/doi/10.1145/3318464.3389766, last accessed November 4, 2022.

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. 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.



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

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Naphade, M., S. Wang, D. C. Anastasiu, Z. Tang, M-C. Chang, Y. Yao, L. Zheng, M. S. Rahman, A. Venkatachalapathy, A. Sharma, Q. Feng, et al. 2022. "The 6th AI City Challenge." 2022 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW). https://doi.org/10.48550/arXiv.2204.10380, last accessed November 7, 2022.

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3. Wang, J., W. Chai, S. Velipasalar, A. Venkatachalapathy, K. L. Tan, A. Haghighat, Y. Adu-Gyamfi, and A. Sharma. 2021. "A Survey of Driver Behavior Analysis From In-Vehicle Cameras." accepted for publication *IEEE Transactions on Intelligent Transportation Systems*.

SUBMITTED FOR PUBLICATION

1. Chai, W., J. Chen, J. Wang, S. Velipasalar, A. Venkatachalapathy, Y. Adu-Gyamfi, J. Merickel, and A. Sharma "Driver Head Pose Detection From Naturalistic Driving Data." submitted to *IEEE Transactions on Intelligent Transportation Systems*.
2. Aboah, A., Y. Adu-Gyamfi, S. V. Gursoy, J. Merickel, M. Rizzo, and A. Sharma. "Driver Maneuver Detection and Analysis Using Time Series Segmentation and Classification." Submitted to *Journal of Transportation Engineering, Part A: Systems*.

SECOND STRATEGIC HIGHWAY RESEARCH PROGRAM (SHRP 2) NATURALISTIC DRIVING STUDY (NDS) VIDEO ANALYTICS RESEARCH

VOLPE NATIONAL TRANSPORTATION SYSTEMS CENTER

A Volpe National Transportation Systems Center research team developed a video-processing tool that uses machine learning to train neural networks to identify and classify roadway features and driving conditions. In phase I of the project, the team focused on detecting and mapping work zone features, such as barrels, cones, and signs. During phase II, the researchers trained neural networks to detect traffic signals and signal states as well as weather events and roadway weather conditions visible in the forward-facing video stream from the SHRP 2 NDS dataset. Once extracted, these data can be added to the SHRP 2 NDS time series, which includes radar and Global Positioning System data, or the roadway information database. Including this information in those databases will enable safety researchers and other stakeholders—such as representatives from the insurance industry or vehicle manufacturers working on advanced transportation solutions like autonomous vehicle development—to more easily access items of interest in the databases. The algorithms developed in this project could also inform future projects focused on other unextracted data, such as detecting and counting lanes, mapping work zone structure, and identifying other roadway features relevant to transportation safety initiatives. The project furthers the original mission of the SHRP 2 NDS data—to find strategic solutions to enhance highway safety, reduce congestion, and improve roadway and bridge renewal—by making the datasets more accessible to end users working on innovating roadway safety.

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Abodo, F., R. Rittmuller, B. Sumner, and A. Berthaume. 2018. "Detecting Work Zones in SHRP 2 NDS Videos Using Deep Learning Based Computer Vision." *17th IEEE International Conference on Machine Learning and Applications (ICMLA)*. Orlando, FL: IEEE. 679–686. https://ieeexplore.ieee.org/document/8614133, last accessed November 7, 2022.
2. Yi, H., C. Bizon, D. Borland, M. Watson, M. Satusky, R. Rittmuller, R. Radwan, R. Srinivasan, and A. Krishnamurthy. 2021. "AI Tool with Active Learning for Detection of Rural Roadside Safety Features." *2021 IEEE International Conference on Big Data (Big Data)*. Orlando, FL: IEEE. 5317–5326. https://ieeexplore.ieee.org/document/9671360/authors#authors, last accessed November 7, 2022.

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 NDS 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.(1)

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Aykac, D., T. Karnowski, R. Ferrell, and J. Goddard. 2020. "Detection and Characterization of Rumble Strips in Roadway Video Logs." *Electronic Imaging* no. 6: 50-1–50-8. 10.2352/ISSN.2470-1173.2020.6.IRIACV-050, last accessed November 7, 2022.

2. Wali, B., A. Khattak, and T. Karnowski. 2020. "The Relationship Between Driving Volatility in Time to Collision and Crash Injury Severity in a Naturalistic Driving Environment." *Analytic Methods in Accident Research* 28, December: 100136. https://doi.org/10.1016/j.amar.2020.100136, last accessed November 7, 2022.
3. Baragchizadeh, A., K. Orsten-Hooge, T. Karnowski, D. Bolme, R. Ferrell, P. Jesudasen, C. Castillo, and A. O'Toole. 2020. "Seeing Through De-Identified Faces in Videos by Humans and a Deep Convolutional Neural Network." *Journal of Vision* 20, no. 11: 757. https://doi.org/10.1167/jov.20.11.757, last accessed November 7, 2022.
4. Orsten-Hooge, K., A. Baragchizadeh, T. Karnowski, D. Bolme, R. Ferrell, P. Jesudasen, C. Castillo, and A. O'Toole. 2020. "Evaluating Automated Face Identity-Masking Methods with Human Perception and a Deep Convolutional Neural Network." *ACM Transactions on Applied Perception* 18, no. 1: 1–20. https://dl.acm.org/doi/abs/10.1145/3422988, last accessed November 7, 2022.
5. Ferrell, R., D. Aykac, T. Karnowski, and N. Srinivas. 2021. *A Publicly Available, Annotated Dataset for Naturalistic Driving Study and Computer Vision Algorithm Development*. Report No. ORNL/TM-2019/1106. Oak Ridge, TN: Oak Ridge National Laboratory. https://info.ornl.gov/sites/publications/Files/Pub122418.pdf, last accessed November 7, 2022.
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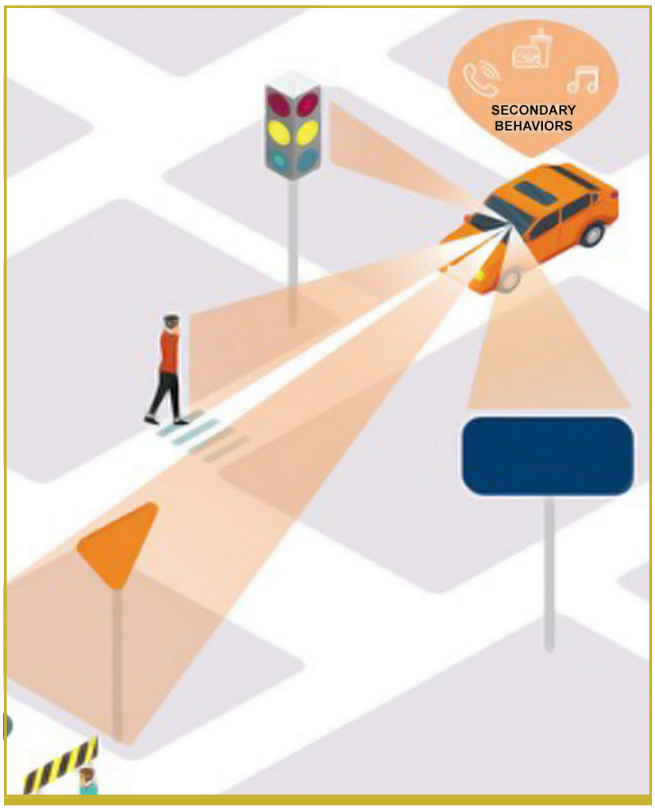
7. Khattak, Z. H., M. Fontaine, W. Li, A. Khattak, and T. Karnowski. 2021. "Investigating the Relation Between Instantaneous Driving Decisions and Safety Critical Events in Naturalistic Driving Environment." *Accident Analysis & Prevention* 156: 106086. https://doi.org/10.1016/j.aap.2021.106086, last accessed November 7, 2022.
8. Karnowski, T., D. Aykac, R. Ferrell, C. Gambrell, Z. Langford, and L. Torkelson. 2022. "Leveraging Gradient Weighted Class Activation Mapping to Improve Classification Effectiveness: Case Study in Transportation Infrastructure Characterization." *Symposium on Electronic Imaging* 34, no. 6: 1–6. https://doi.org/10.2352/EI.2022.34.6.IRIACV-275, last accessed November 7, 2022.
9. Liu, A., A. Boka, A. Baragchizadeh, C. Muthukumar, V. Huang, A. Sarup, R. Ferrell, G. Friedland, T. Karnowski, M. Lee, and A. O'Toole. 2021. "Driving Road Safety Forward: Video Data Privacy Task" presented at *MediaEval 2021*. Bergen, Norway: MediaEval. https://www.osti.gov/servlets/purl/1879957, last accessed November 7, 2022.



Computer vision can annotate secondary behaviors inside the vehicle, extravehicular context, and interactions between the driver and the environment.

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 SHRP 2 NDS database using the continuous videos. The study aimed to make it easier for researchers to create smaller subsets of data subsets from the more than 1 million hours of video data that make up the SHRP 2 NDS database. The research team developed and evaluated a series of deep neural network models (including convolutional neural network and RNN) 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. Sundharam, V., A. Sarkar, J. Hickman, and L. Abbott. 2022, Accepted. "Characterization, Detection, and Segmentation of Work Zone Scenes from Naturalistic Driving Data." *Transportation Research Record*.
2. Winkowski, C., A. Sarkar, J. Hickman, and L. Abbott. 2022, Accepted. "Residual Network-Based Driver Gaze Classification in Naturalistic Driving Studies." *Transportation Research Record*.
3. Papakis, I., A. Sarkar, A. Svetovidov, J. S. Hickman, and A. L. Abbott. 2021. "Convolutional Neural Network-Based In-Vehicle Occupant Detection and Classification Method Using Second Strategic Highway Research Program Cabin Images." *Transportation Research Record* 2675, no. 8: 443–457. https://doi.org/10.1177/03611981219986, last accessed November 7, 2022.

CONFERENCE PROCEEDINGS LEADING TO BOOK CHAPTERS

1. Sarkar, A. 2022. "A Comprehensive Safety Analysis for Gaze Fixation of Drivers to Outside Scene." Presented at *Human Factors in Transportation. AHFE (2022) International Conference.* New York, NY. In *Applied Human Factors and Ergonomics Open Access, vol 60.* eds. Katie Plant and Gesa Praetorius. Applied Human Factors and Ergonomics International. http://doi.org/10.54941/ahfe1002481, last accessed November 8, 2022.
2. Sarkar, A. 2022. "Visual Dictionary of Human Action in Vehicular Environment Using Computer Vision." Presented at *Human Factors in Transportation. AHFE (2022) International Conference.* New York, NY. In *Applied Human Factors and Ergonomics Open Access, vol 60.* eds. Katie Plant and Gesa Praetorius. Applied Human Factors and Ergonomics International. http://doi.org/10.54941/ahfe1002446, last accessed November 8, 2022.

CONFERENCE PRESENTATIONS

1. Sarkar, A. 2022. "Visual Dictionary of Human Action in Vehicular Environment Using Computer Vision." In *13th International Conference on Applied Human Factors and Ergonomics*. New York, NY: Applied Human Factors and Ergonomics International.
2. Sarkar, A. 2022. "A Comprehensive Safety Analysis for Gaze Fixation of Drivers to Outside Scene." In *13th International Conference on Applied Human Factors and Ergonomics* (Accepted). New York, NY: Applied Human Factors and Ergonomics International.
3. Datta, D., A. Sarkar, C. Winkowski, L. Abbott, J. Hickman, M. Camden, and J. Sudweeks. 2022. "Detecting Gaze Location From Temporal Relations of Driver Face Pose Using Recurrent Neural Network." Presented at *Transportation Research Board 101st Annual Meeting*. Washington, DC: Transportation Research Board.
4. Winkowski, C., A. Sarkar, A. Svetovidov, J. Hickman, and L. Abbott. 2022. "Residual Network-Based Driver Gaze Classification in Naturalistic Driving Studies." Presented at *Transportation Research Board 101st Annual Meeting*. Washington DC: Transportation Research Board.
5. Sundharam, V., A. Sarkar, A. Svetovidov, J. Hickman, and L. Abbott. 2022. "Characterization, Detection, and Segmentation of Work Zone Scenes From Naturalistic Driving Data." Presented at *Transportation Research Board 101st Annual Meeting*. Washington DC: Transportation Research Board.
6. Papakis, I., A. Sarkar, A. Svetovidov, J. Hichman, and L. Abbott. 2021. "A CNN-Based In-Vehicle Occupant Detection and Classification Method Using SHRP 2 Cabin Images." Presented at *Transportation Research Board 100th Annual Meeting*. Washington DC: Transportation Research Board.

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. 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. These projects aim to provide State departments of transportation (DOT) 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, are seeking to develop what they're calling "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 aims 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.

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

ACCEPTED FOR PUBLICATION

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2. Oey, T., S. Jones, J. W. Bullard, and G. Sant. 2020. "Machine Learning Can Predict Setting Behavior and Strength Evolution of Hydrating Cement Systems." *Journal of the American Ceramic Society* 103, 480–490. https://doi.org/10.1111/jace.16706, last accessed November 7, 2022.
3. Liu, H., Z. Fu, K. Yang, X. Xu, and M. Bauchy. 2019. "Machine Learning for Glass Science and Engineering: A Review." *Journal of Non-Crystalline Solids* 557, 119419. https://doi.org/10.1016/j.jnoncrysol.2019.04.039, last accessed November 7, 2022.
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NONTRADITIONAL AND NATURAL POZZOLAN-BASED SCMS OR INORGANIC POLYMERS FOR TRANSPORTATION INFRASTRUCTURE

PURDUE UNIVERSITY

While fly ash is a dominant choice among SCMs, there are other types of materials that could also be used for concrete production. These other materials include nontraditional and natural pozzolans. 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 these types of SCMs might perform in concrete pavements or other transportation structures. 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. Yoon, J., K. Jafari, R. Tokpatayeva, S. Peethamparam, 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 November 8, 2022.

PERFORMANCE-BASED CLASSIFICATION METHODS FOR RECLAIMED FLY ASH

OKLAHOMA STATE UNIVERSITY

Much of the fly ash used in concrete production is of a certain specification grade. But there are landfills and impoundments of other, older fly ash that have been stored over the last 50 to 60 yr. It is that fly ash—called "reclaimed" fly ash—that researchers want to study to see if they provide viable alternatives to the approved fly ash sources currently in use. Researchers at Oklahoma State University, with help from the Georgia Institute of Technology, Ohio State University, and Diversified Engineering Services, seek to combine advanced material characterization methods, performance-based testing, mechanistic modeling, and machine learning to create engineering tools to classify reclaimed fly ash. Also involved in the project as collaborators are Boral Materials, the Minnesota Department of Transportation, the Oklahoma DOT, and Southern Company. The project involves taking existing performance-based tests, tweaking them to better analyze the reclaimed fly ash, and determining how it might perform when used for concrete production. The researchers want to capture the differences in chemical composition among the various reclaimed fly ashes and see how those differences can be measured in a way that describes how that fly ash performs 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 November 7, 2022.
2. Kang, S., Z. Lloyd, A. Behravan, and M. T. Ley. 2021. "The Relationship Between the Apparent Diffusion Coefficient and Surface Resistivity of Fly Ash Concrete." *Construction and Building Materials* 299: 123964. https://doi.org/10.1016/j.conbuildmat.2021.123964, last accessed November 7, 2022.
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5. Kang, S., Z. Lloyd, T. Kim, and M. T. Ley. 2020. "Predicting the Compressive Strength of Fly Ash Concrete with the Particle Model." *Cement and Concrete Research* 138: 106218. https://doi.org/10.1016/j.cemconres.2020.106218, last accessed November 7, 2022.
6. Kim, T., M. T. Ley, S. Kang, J. M. Davis, S. Kim, and P. Amrollahi. 2020. "Using Particle Composition of Fly Ash to Predict Concrete Strength and Electrical Resistivity." *Cement and Concrete Composites* 107: 103493. https://doi.org/10.1016/j.cemconcomp.2019.103493, last accessed November 7, 2022.

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 (TSMO) solutions for freeway systems based on cooperative driving automation (CDA). 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. Xu, R., H. Xiang, Z. Tu, X. Xia, M-H. Yang, and J. Ma. 2022. "V2X-ViT: Vehicle-to-Everything Cooperative Perception with Vision Transformer." Accepted for publication European Conference on Computer Vision ECCV2022.

Interagency Research

The following projects were jointly funded by the Federal Highway Administration's (FHWA) EAR Program and the National Science Foundation (NSF).

TRAFFIC OPERATING SYSTEM FOR SMART CITIES

UNIVERSITY OF CALIFORNIA (UC) BERKELEY

In addition to minimizing congestion and reducing driver errors, the CPS research at UC Berkeley aims to curtail collisions at intersections and to contain the costs of city parking by reducing the time it takes to find open spots. To achieve these goals, researchers use existing automotive, communication, and computation tools to manage traffic at three levels—the vehicle, the road link, and the network link. The options include adjusting the speed and headway of automated vehicles, optimizing the timing of traffic signals and special lanes (like opening high-occupancy vehicle lanes to all traffic), and setting traffic signals to favor traffic on particular routes at specific times. The UC Berkeley team is collecting field data in two locations—Arcadia, CA, and North Bethesda, MD. At the Maryland location, researchers are pulling data from actual traffic as it moves through eight intersections, and they are building simulation models based on those real-life situations. (NSF award 15-45116)

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Li, R., P. Brown, and R. Horowitz. 2021. "Employing Altruistic Vehicles at On-Ramps to Improve the Social Traffic Conditions." Presented at *American Control Conference*. New Orleans, LA: IEEE.
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3. Arcak, M., and N. Martins. 2021. "Dissipativity Tools for Convergence to Nash Equilibria in Population Games." *IEEE Transactions on Control of Network Systems* 8, no. 1: 30–50. https://ieeexplore.ieee.org/document/9219202, last accessed November 8, 2022.

TRAFFIC SIGNAL CONTROL WITH CONNECTED AND AUTONOMOUS VEHICLES IN THE TRAFFIC STREAM

UNIVERSITY OF FLORIDA

As America's urban population multiplies, so does the number of cars on city streets. The resulting congestion can contribute to increased or unreliable travel time. The emergence of highly automated vehicles could help improve urban mobility if the cars can be safely integrated into cyber physical systems (CPS) that also include technologically advanced traffic signals and road sensors.[2,3]

This self-driving vehicle, named NaviGator, is part of the University of Florida's research on cyber physical systems. © University of Florida.

The CPS research at the University of Florida seeks to develop signal control strategies by optimizing the technology in automated vehicles and other sensor mechanisms. The researchers are developing algorithms that obtain the locations, directions, and speeds of vehicles as they enter the communications range of an intersection; send that data to the traffic signal; and calculate the best approach trajectories for each vehicle. By optimizing the signal timing, this approach can improve traffic flow and minimize travel time. Twice in 2017, the researchers tested some computer simulations on a closed-course intersection at the Florida DOT's Traffic and Engineering Research Lab in Tallahassee, FL. Based on the lessons learned, the team is enhancing the algorithm to implement a testbed on the university's Gainesville, FL, campus. The researchers are working to improve the accuracy of the information they receive from sensors and extend the communications range so they can gather data from vehicles farther from the intersection. (NSF award 14-46813)

ACCEPTED FOR PRESENTATIONS

1. Emami, P., P. He, S. Ranka, A. Rangarajan. 2021. "Efficient Iterative Amortized Inference for Learning Symmetric and Disentangled Multi-Object Representations." Presented at the *38th International Conference on Machine Learning*. Virtual.

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. 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 will develop algorithms based on human behavior that will help vehicles and humans safely and efficiently pass through an intersection. The next phase of the research project will involve experimenting with these algorithms with 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. 2021. "Parallelized Active Information Gathering Using Multisensor Network for Environment Monitoring." *IEEE Transactions on Control Systems Technology* 30, no. 2: 625–638. https://ieeexplore.ieee.org/document/9420289, last accessed November 8, 2022.

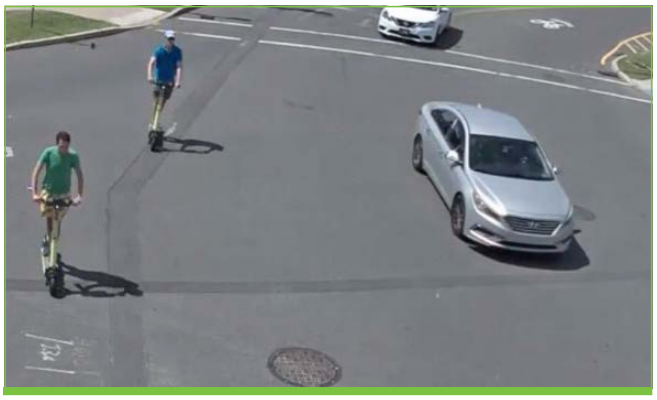
IDENTIFYING, CHARACTERIZING, AND SHAPING MULTI-SCALE CYBER-HUMAN INTERACTIONS IN MIXED AUTONOMOUS/CONVENTIONAL VEHICLE TRAFFIC

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. 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., and D. Negrut. 2021. "Modeling Cameras for Autonomous Vehicle and Robot Simulation: An Overview." *IEEE Sensors Journal* 21, no. 22: 25547–25560. https://ieeexplore.ieee.org/abstract/document/9564034, last accessed November 8, 2022.
2. Elmquist, A., R. Serban, and D. Negrut. 2021. "A Sensor Simulation Framework for Training and Testing Robots and Autonomous Vehicles." *Journal of Autonomous Vehicles and Systems* 1, no. 2. 021001. https://doi.org/10.1115/1.4050080, last accessed November 8, 2022.



E-scooters being used alongside car traffic.

3. Liu, C. K., and D. Negrut. 2021. "The Role of Physics-Based Simulators in Robotics." *Annual Review of Control, Robotics, and Autonomous Systems* 4: 35–58. https://doi.org/10.1146/annurev-control-072220-093055, last accessed November 8, 2022.

MAKING MICROMOBILITY SMARTER AND SAFER (M2S2)

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. From 2010 to 2019, shared micromobility vehicle ridership ballooned from 321,000 trips annually in 2010 to 136 million annually in 2019.(2) In 2020, travelers in the United States took an estimated 67.9 million trips on shared micromobility vehicles.(3) 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. Noland, R. B. 2021. "Scootin' in the Rain: Does Weather Affect Micromobility?" *Transportation Research Part A: Policy and Practice* 149, 114–123. https://doi.org/10.1016/j.tra.2021.05.003, last accessed November 8, 2022.
2. Zhang, T. T., M. Guo, P. J. Jin, Y. Ge, and J. Gong. 2021. "Longitudinal-Scanline-Based Arterial Traffic Video Analytics with Coordinate Transformation Assisted by 3D Infrastructure Data." *Transportation Research Record: Journal of the Transportation Research Board* 2675, no 3. https://doi.org/10.1177/0361198120971257, last accessed November 8, 2022.

The researchers are using cameras to capture traffic data.

HYBRID TWINS FOR URBAN TRANSPORTATION: FROM INTERSECTIONS TO CITYWIDE MANAGEMENT

COLUMBIA UNIVERSITY

Traffic management in metropolitan areas poses distinct challenges. 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. (NSF award 20-38984)

ACCEPTED FOR PUBLICATION AND PRESENTATIONS

1. Ghasemi, M., Z. Yang, M. Sun, H. Ye, Z. Xiong, J. Ghaderi, Z. Kostic, and G. Zussman. 2021. "Video-Based Social Distancing Evaluation in the Cosmos Testbed Pilot Site." MobiCom '21: *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking*. 874–876. New York, NY: Association for Computing Machinery. https://doi.org/10.1145/3447993.3510590, last accessed November 8, 2022.
2. Ghasemi, M., S. Kleisarchaki, T. Calmant, L. Gürgen, J. Ghaderi, Z. Kostic, and G. Zussman. 2022. "Real-Time Camera Analytics for Enhancing Traffic Intersection Safety." in MobiSys '22: *Proceedings of the 20th Annual International Conference on Mobile Systems, Applications and Services*. 630–631. New York, NY: Association for Computing Machinery. https://doi.org/10.1145/3498361.3538669, last accessed November 8, 2022.
3. Duan, Z., Z. Yang, R. Samoilenko, D. S. Oza, A. Jagadeesan, M. Sun, H. Ye, Z. Xiong, G. Zussman, and Z. Kostic. 2022. "Smart City Traffic Intersection: Impact of Video Quality and Scene Complexity on Precision and Inference." *19th International Conference on Smart City*. Haikou, Hainan, China: IEEE. https://ieeexplore.ieee.org/document/9781018, last accessed November 8, 2022.
4. Kostic, Z., A. Angus, Z. Yang, Z. Duan, I. Seskar, G. Zussman, D. Raychaudhuri. 2022. "Smart City Intersections: Intelligence Nodes for Future Metropolises." https://arxiv.org/pdf/2205.01686.pdf, last accessed November 8, 2022.
5. Yang, Z., M. Sun, H. Ye, Z. Xiong, G. Zussman, Z. Kostic. 2022. "Bird's-Eye View Social Distancing Analysis System." *2022 IEEE International Conference on Communications Workshop on Edge Learning for 5G Mobile Networks and Beyond*. Seoul, South Korea: IEEE. https://ieeexplore.ieee.org/document/9814627, last accessed November 8, 2022.

Research Associateship Program (RAP)

FHWA's Turner-Fairbank Highway Research Center (TFHRC) conducts research across a wide range of topics and disciplines. To supplement the expertise of the permanent staff, it is important to bring in researchers with the appropriate backgrounds to investigate specific problems on a short-term basis. Through the EAR Program, FHWA utilizes the RAP of the National Academy of Sciences (formerly the National Research Council (NRC)) for this purpose. The National Academy of Sciences provides a process for selecting candidates on a competitive merit basis and (subsequently) for the administration of the resident fellows during their tenures at FHWA.

Through RAP, the EAR Program:

- Provides postdoctoral scientists and engineers who show unusual ability and promise an opportunity to conduct research—on problems largely of their personal choice—that is compatible with the research interests of TFHRC.
- Contributes to the general research efforts of TFHRC.

RAP provides postdoctoral candidates the opportunity to spend 2 or 3 yr working on leading-edge transportation research in world-class facilities with top-notch experts. Research associates are matched with an FHWA adviser who mentors them throughout the program.

RAPHAEL ISOKPEHI, PH.D.

During his 12-mo RAP tenure, Raphael Isokpehi focused on applying big data techniques to pavement management. In his project, titled "Leveraging Big Data for Enhanced Pavement Management," Dr. Isokpehi considered diverse data types for pavement management, a wide range of technologies for measuring attributes of a pavement network, an effective collection of massive amounts of data at traffic speed, and auxiliary data's increased availability.

Dr. Isokephi engaged and established collaboration with pavement management experts through participation in conferences. The research team collaborated with other pavement engineers and researchers in the public and private sectors as well as academia through the Transportation Pooled Fund study "Pavement Structural Evaluation with Traffic Speed Deflection Devices" and the Big Data for Smart Pavement Management and Deflection at Road Traffic Speed User Group.

ACCEPTED FOR PRESENTATIONS

1. Isokpehi, R., A. Nadkarni, and N. Sivaneswaran. 2022. "Big Data Investigations to Knowledge for Enhanced Pavement Management." Presented at pre-conference workshop at *ICMPA 2022—11th International Conference on Managing Pavement Assets*. Chicago, IL: Transportation Research Board.
2. Isokpehi, R., A. Nadkarni, and N. Sivaneswaran. 2022. "Big Data Investigations to Knowledge for Enhanced Pavement Management." Presented at the 16th Deflection at Road Traffic Speed User Group meeting held in conjunction with the *Transportation Research Board 101st Annual Meeting*. Washington DC: Transportation Research Board.

HENG LIU, PH.D.

During his RAP tenure, Heng Liu developed two condition forecast models for the FHWA Long-Term Bridge Performance InfoBridge™ web portal. He also published one peer-reviewed journal paper and made several presentations at the Transportation Research Board Annual Meeting and various FHWA meetings and webinars.

ACCEPTED FOR PUBLICATION

1. Liu, Heng. 2022. "Performance Forecasts of US Highway Bridge Networks Using Generalized Poisson–Binomial Distribution." *ASCE Journal of Infrastructure Systems* 28, no. 4. https://doi.org/10.1061/(ASCE)IS.1943-555X.0000710, last accessed November 7, 2022.
2. Liu, H., J. Nehme, and P. Lu. 2021. "An Application of Convolutional Neural Network for Deterioration Modeling of Highway Bridge Components in the United States." *Structure and Infrastructure Engineering*. https://www.tandfonline.com/doi/full/10.1080/15732479.2021.1979597, last accessed November 7, 2022.

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1. Federal Highway Administration. 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.

2. 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.

3. 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.

Recommended citation: Federal Highway Administration, *Exploratory Advanced Research (EAR) Program Compendium of Papers from Funded Research Projects* (Washington, DC: 2023) https://doi.org/10.21949/1521965.

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