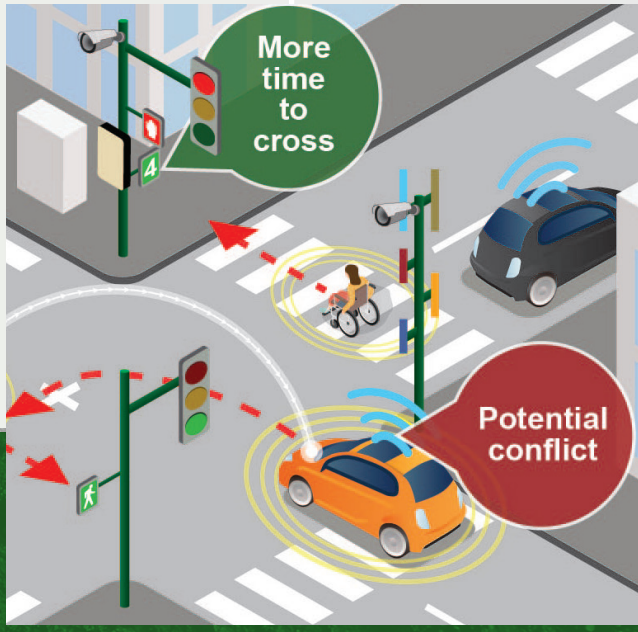
Exploratory Advanced Research (EAR) Program

Compendium of Papers From Funded Research Projects

Updated for 2024

EXPLORATORY ADVANCED RESEARCH



U.S. Department of Transportation
Federal Highway Administration

Notice

This document is disseminated under the sponsorship of the U.S. Department of Transportation (USDOT) in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document.

Non-Binding Contents

Except for the statutes and regulations cited, the contents of this document do not have the force and effect of law and are not meant to bind the States or the public in any way. This document is intended only to provide information regarding existing requirements under the law or agency policies.

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.

Disclaimer for Product Names and Manufacturers

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. They are included for informational purposes only and are not intended to reflect a preference, approval, or endorsement of any one product or entity.

TABLE OF CONTENTS

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.[1] 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 Presentation

Liu, S., H. Shen, B. Smith, and V. Fessmann. 2023. "Machine Learning-Based Intelligent Routing for VDTNs." In *2023 32nd International Conference on Computer Communications and Networks (ICCCN)*. Piscataway, NJ: IEEE. 1–10.

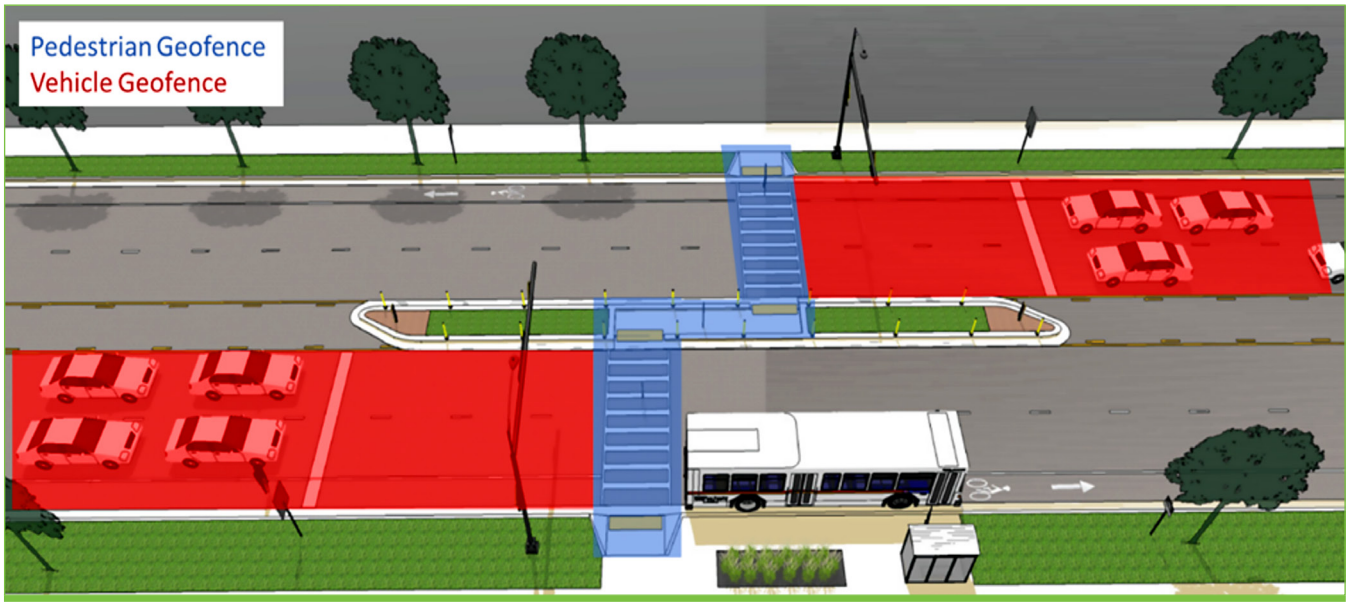
HARNESSING MOBILE AD HOC NETWORKS TO IMPROVE VULNERABLE ROAD USER SAFETY

University of Wisconsin–Madison

Researchers for this project looked to harness MANETs to alert vehicles to pedestrian and bicyclist crossings at intersections through a mobile application.[1] The project developed a system to alert a driver's smartphone by a message sent from the smartphone of a pedestrian who is about to cross the street. By receiving this notification, a car can slow down or change course more safely in time to avoid a collision.

Accepted for Publication and Presentation

Wu, Z., C.-Y. Huang, and P. Ramanathan. 2023. "MIA: A Transport-Layer Plugin for Immersive Applications in Millimeter Wave Access Networks." In *IEEE INFOCOM 2023 - IEEE Conference on Computer Communications*. Piscataway, NJ: IEEE. 1–10.



Transportation researchers explored methods of implementing MANETs to enhance communication between vehicles and nonmotorized travelers.[1]

DIGITAL TWINS

DIGITAL TWIN-ENABLED EXTENDED ACTIVE SAFETY ANALYSIS FOR MIXED TRAFFIC

Texas A&M Transportation Institute

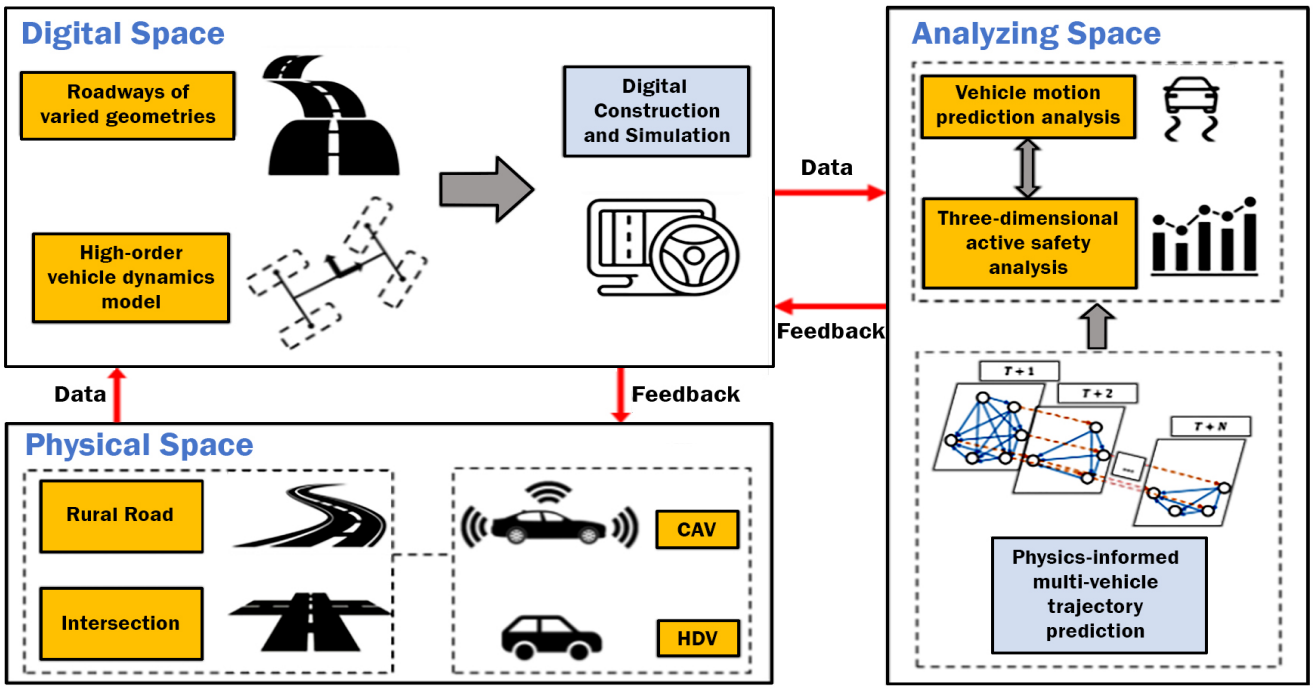
Traffic safety is a primary focus for policymakers and transportation researchers. At the Texas A&M Transportation Institute, researchers are developing a novel framework for traffic safety analysis.[2] The 3-yr study seeks to build a predictive, extended active safety approach for mixed traffic of human-driven vehicles and connected and automated vehicles through a digital twin technique, which creates a virtual replica of a physical object, system, or process, helping researchers understand real-world performance.

Accepted for Publication

1. Li, S., M. Anis, D. Lord, H. Zhang, Y. Zhou, and X. Ye. 2024. "Beyond 1D and Oversimplified Kinematics: A Generic Analytical Framework for Surrogate Safety Measures." *Accident Analysis & Prevention* 204: 107649. https://www.sciencedirect.com/science/article/abs/pii/S0001457524001945, last accessed October 4, 2024.
2. Li, Z., Y. Zhou, D. Chen, and Y. Zhang. 2024. "Disturbances and Safety Analysis of Linear Adaptive Cruise Control for Cut-In Scenarios: A Theoretical Framework." *Transportation Research Part C: Emerging Technologies* 104576. https://www.sciencedirect.com/science/article/abs/pii/S0968090X24000974, last accessed October 4, 2024.

Submitted for Publication and Presentation

1. Anis, M., S. Li, S. R. Geedipally, Y. Zhou, and D. Lord. 2024. "Real-Time Risk Estimation for Active Road Safety: Leveraging Waymo AV Sensor Data With Hierarchical Bayesian Extreme Value Models." Presentation at the Transportation Research Board Annual Meeting 2025.
2. Wu, K., H. Shi, Y. Zhou, and R. Bin. 2024. "Hypergraph-Based Motion Generation and Planning With Multi-Modal Interaction Relational Reasoning." Presentation at the Transportation Research Board Annual Meeting 2025.



© Yang Zhou.
Digital twin active safety system.[2]

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.[3] 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.[4] These projects aim to provide State departments of transportation (DOTs) 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.

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.[4] 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 and Presentation

1. Castillo, A., R. Tokpatayeva, B. Zhaksybay, and J. Olek. 2024. “Comparison of Mechanical and Durability Properties of Lab and Field-Cured Concretes With Fly Ash and Nontraditional Pozzolans.” Presented at the *ACI Concrete Convention*. Philadelphia, PA: American Concrete Institute.
2. Castillo, A., R. Tokpatayeva, B. Zhaksybay, and J. Olek. 2024. “Field Evaluation of Natural Pozzolans (NPs) in Concrete for Pavement Applications.” Presented at the *13th International Conference on Concrete Pavements*. Minneapolis, MN: International Society for Concrete Pavements.
3. Castillo, A., R. Tokpatayeva, B. Zhaksybay, and J. Olek. 2024. “Mechanical and Durability Capabilities of Field Concrete Incorporating Nontraditional and Natural Pozzolans (NNPs).” Presented at the *Trailblazers in Engineering Workshop*. West Lafayette, IN: Purdue University.
4. Sharbaf, M., and F. Rajabipour. 2024. “A New Soluble Alkali Test for Supplementary Cementitious Materials.” In *Proceedings of the 17th International Conference on Alkali-Aggregate Reaction in Concrete (ICAAR)*. Edited by L. F. M. Sanchez and C. Trottier. RILEM Bookseries, vol. 49. Cham, Switzerland: Springer. 379–387.
5. Zhaksybay, B., A. Castillo, R. Tokpatayeva, and J. Olek. 2024. “Performance of Nontraditional SCMs (NNPs) in Concrete Field Mixtures.” Presented at the *ACI Concrete Convention*. New Orleans, LA: American Concrete Institute.
6. Zhussupbekova, A., A. Castillo, and J. Olek. 2024. “Potential Incompatibilities Between Admixtures and Nontraditional and Natural Pozzolans (NNPs) in Cementitious Systems.” Presented at the *Spring Purdue Undergraduate Research Conference*. West Lafayette, IN: Purdue University.

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.[4] 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

Min, Y., E. Stewartson, P. Suraneni, C. R. Shearer, R. D. Hooton, and L. E. Burris. 2024. "Measuring Concrete Air-Entraining Admixture Adsorption on Coal Ash Using Three-Phase Equilibrium and Fluorescence-Based Methods." *CEMENT* 18: 100115. https://doi.org/10.1016/j.cement.2024.100115, last accessed October 4, 2024.

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.[5] 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 Presentation

1. Garita-Jimenez, J., N. Tran, F. Keuliyan, R. Moraes, C. Rodezno, and F. Yin. 2024. "Evaluating Aging Resistant Technologies for Enhancing Cracking Resistance of Asphalt Mixtures." Presented at the *103rd Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.

2. Garita-Jimenez, J., N. H. Tran, F. Keuliyan, R. Moraes, C. Rodezno, and F. Yin. 2024. "Innovative Rheological Modifiers for Decreasing the Cracking Susceptibility of Asphalt Mixtures." *Transportation Research Record*. https://journals.sagepub.com/doi/abs/10.1177/03611981241264277, last accessed October 7, 2024.

ARTIFICIAL INTELLIGENCE

COOPERATIVE PERCEPTION AND CONTROL FOR FREEWAY TRAFFIC SYSTEM OPERATIONS

University of Cincinnati and the University of California, Los Angeles

The research team is working to develop next-generation Traffic System Management and Operations solutions for freeway systems based on cooperative driving automation.[6] 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 (AI) 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 Presentation

1. Gao, L., X. Xia, Z. Zheng, H. Xiang, Z. Meng, X. Han, Z. Zhou, et al. 2024. "Cooperative Localization in Transportation 5.0." *IEEE Transactions on Intelligent Vehicles* 9, no. 3: 4259–4264. https://ieeexplore.ieee.org/document/10472068, last accessed October 7, 2024.

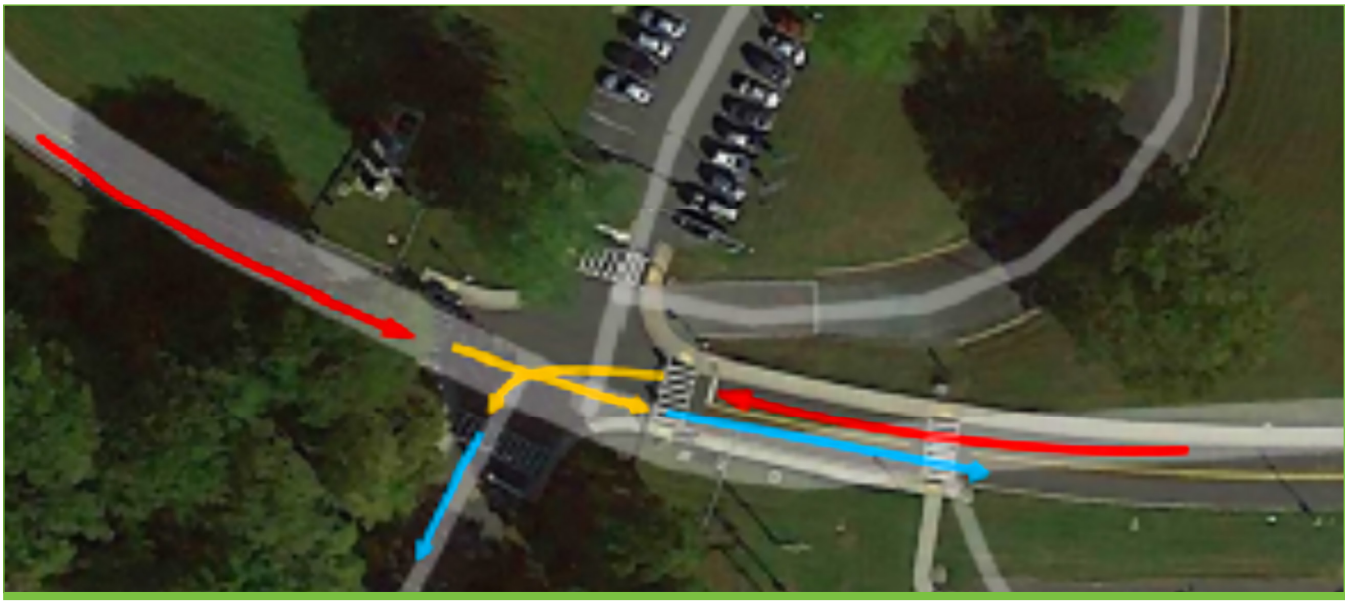
2. Gao, L., H. Xiang, X. Xia, and J. Ma. 2024. "End-to-End Cooperative Localization Via Neural Feature Sharing." In *2024 IEEE Intelligent Vehicles Symposium (IV)*. Piscataway, NJ: IEEE, 553–558. https://ieeexplore.ieee.org/document/10588492, last accessed October 7, 2024.

3. Gao, L., H. Xiang, X. Xia, and J. Ma. 2024. "Multi-Sensor Fusion for Vehicle-to-Vehicle Cooperative Localization With Object Detection and Point Cloud Matching." *IEEE Sensors Journal* 24, no. 7: 10865–10877. https://ieeexplore.ieee.org/document/10440012, last accessed October 7, 2024.

4. Meng, Z., X. Xia, and J. Ma. 2024. "Toward Foundation Models for Inclusive Object Detection: Geometry- and Category-Aware Feature Extraction Across Road User Categories." In *IEEE Transactions on Systems, Man, and Cybernetics: Systems*. Piscataway, NJ: IEEE. https://ieeexplore.ieee.org/document/10507865, last accessed October 7, 2024.

5. Xiang, H., Z. Zheng, X. Xia, R. Xu, L. Gao, Z. Zhou, X Han, et al. 2024. "V2X-Real: A Large-Scale Dataset for Vehicle-to-Everything Cooperative Perception." Accepted by the European Conference on Computer Vision (ECCV) 2024.

6. Zheng, Z., X. Xia, L. Gao, H. Xiang, and J. Ma. 2024. "CooperFuse: A Real-Time Cooperative Perception Fusion Framework." In *2024 IEEE Intelligent Vehicles Symposium (IV)*. Piscataway, NJ: IEEE, 533–538. https://ieeexplore.ieee.org/document/10588758, last accessed October 7, 2024.



Source: FHWA.

Transportation systems management and operations testing scenarios. The arrows show the intended path of travel for each vehicle optimizing its approach to the intersection.[6]

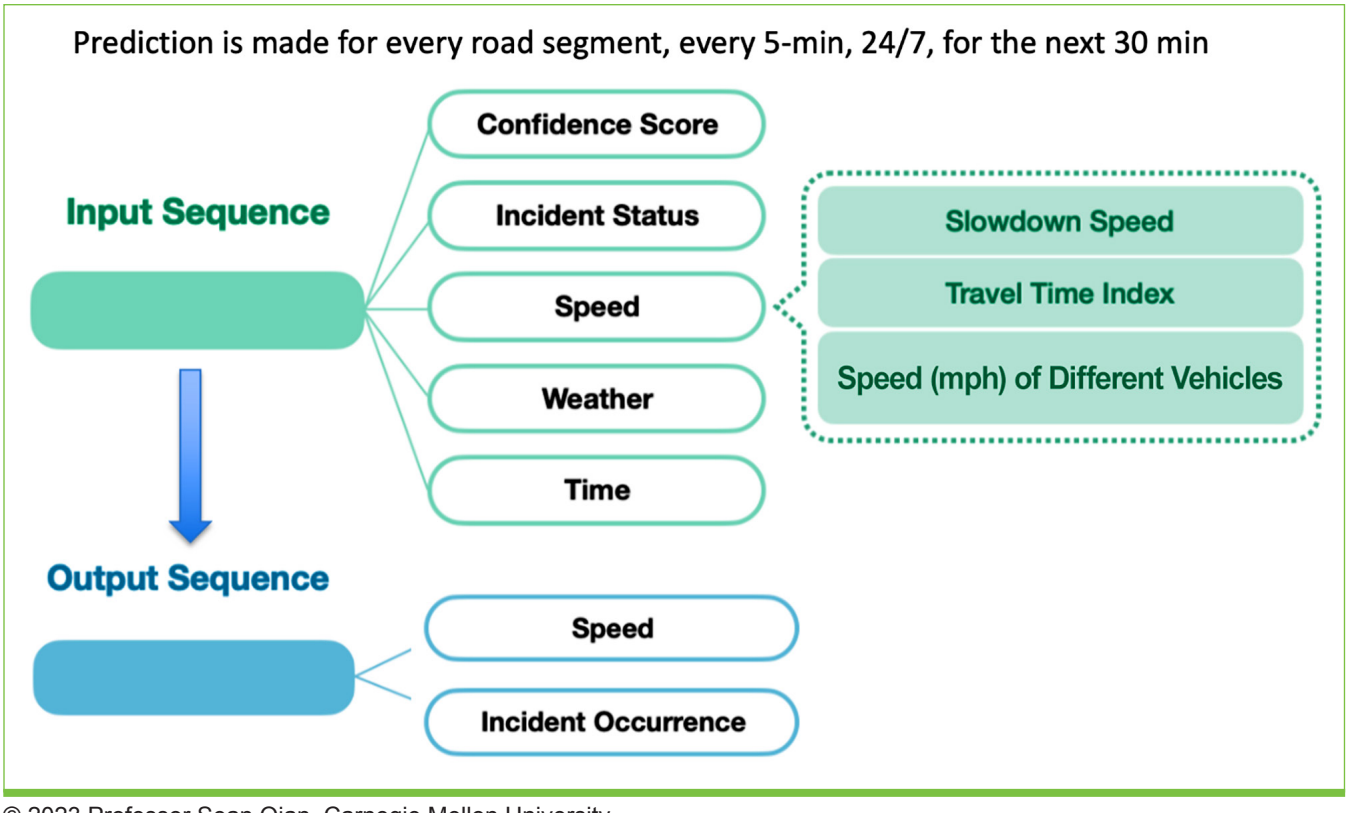
PREDICTIVE REAL-TIME TRAFFIC MANAGEMENT IN LARGE-SCALE NETWORKS USING MODEL-BASED ARTIFICIAL INTELLIGENCE

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.[7] 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 AI 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.

Submitted for Publication and Presentation

1. Duan, H., and S. Qian. 2024. "Know Unreported Roadway Incidents in Real-time: Early Traffic Anomaly Detection." Submitted to the Transportation Research Board Annual Meeting 2025.
2. Ke, Z., H. Duan, and S. Qian. 2024. "Interpretable Mixture of Experts for Time Series Prediction Under Recurrent and Non-Recurrent Conditions." Submitted to the Transportation Research Board Annual Meeting 2025.



Traffic management predictive model.[7]

TRAFFIC INCIDENT DETECTION AND ANALYSIS SYSTEM

Tufts University

Researchers at Tufts University and the City College of New York are leveraging AI to improve the detection of highway incidents.[8] 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 Presentation

1. Frants, V., and S. Agaian. 2024. “Enhancing Robustness of Weather Removal: Preprocessing-Based Defense Against Adversarial Attacks.” In *Multimodal Image Exploitation and Learning 2024* 13033: 172–181. https://doi.org/10.1117/12.3019864, last accessed October 28, 2024.
2. Jinadu, O., V. Oludare, S. Rajeev, L. Kezebou, K. Panetta, and S. Agaian. 2023. “Instant-Level Vehicle Speed and Traffic Density Estimation Using Deep Neural Network.” In *Multimodal Image Exploitation and Learning 2023* 12526: 125–138. https://doi.org/10.1117/12.2663643, last accessed October 28, 2024.
3. Jinadu, O., S. Rajeev, K. Panetta, and S. S. Agaian. 2024. “An Impact Study of Deep Learning-Based Low-Light Image Enhancement in Intelligent Transportation Systems.” In *Multimodal Image Exploitation and Learning 2024* 13033: 154–171. https://doi.org/10.1117/12.3014452, last accessed October 28, 2024.
4. Kaplan, L., V. Frants, and S. Agaian. 2024. “Comprehensive Urban Navigation and Yielding: Video Dataset for Enhanced Collision and Anomaly Detection in Real-World Traffic Scenarios.” In *Multimodal Image Exploitation and Learning 2024* 13033: 182–192. https://doi.org/10.1117/12.3020191, last accessed October 28, 2024.

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

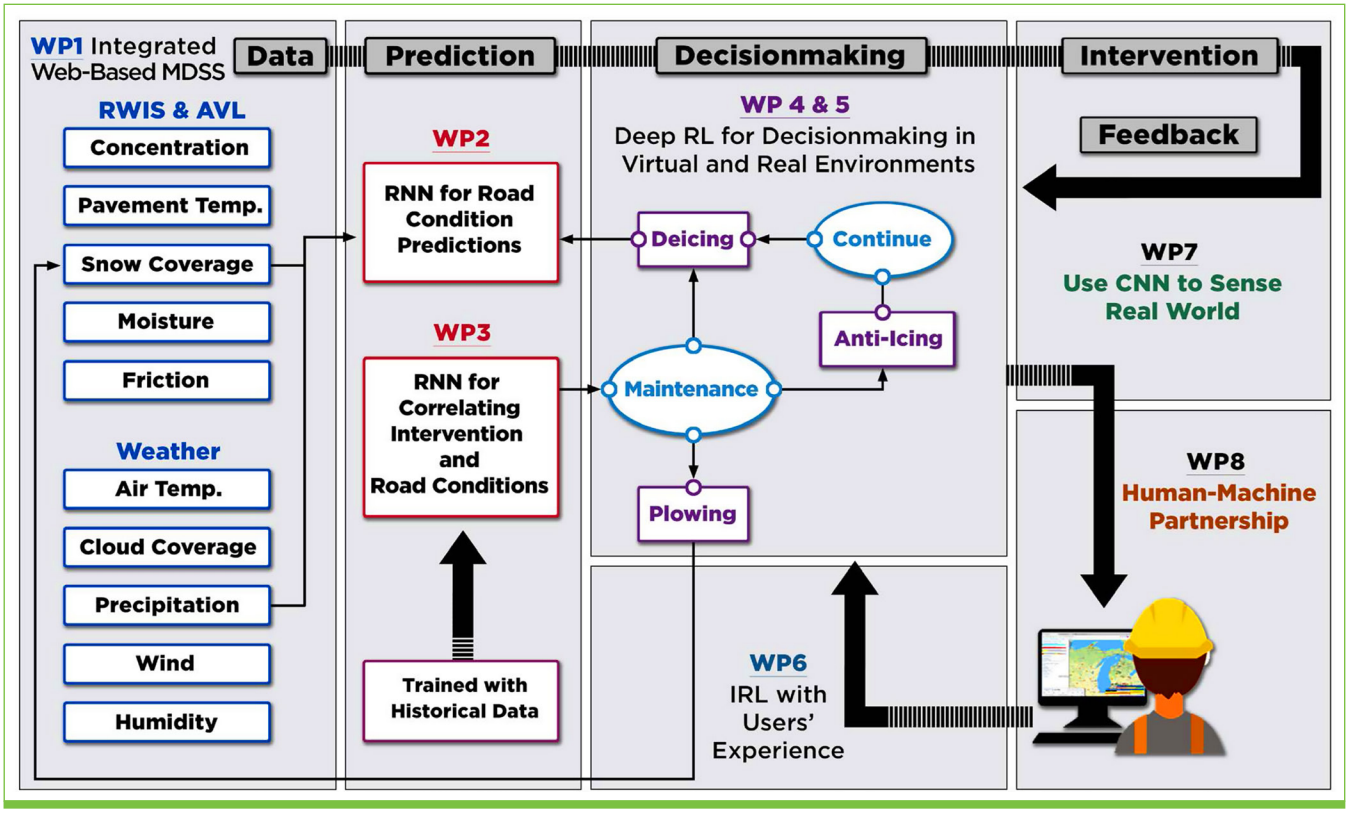
Michigan Technological University

Researchers at the Michigan Technological University are investigating the potential to shift winter maintenance decisionmaking from a model-driven to an AI-enhanced framework.[9] The researchers are developing a data-driven maintenance decision support system to help State 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 Presentation

1. Biniyaz, A., and Z. Liu. 2024. "Multi-Step Ahead Prediction of Freezing Depth Via Deep Learning With Long Short-Term Memory." In *Geo-Congress 2024*. Washington, DC: American Society of Civil Engineers. 742–750.
2. Liu, Z. 2024. *Artificial Intelligence for Engineers*. New York, NY: Springer. In press.



Overview of the autonomous winter road maintenance project, forming a closed-loop approach.[9]

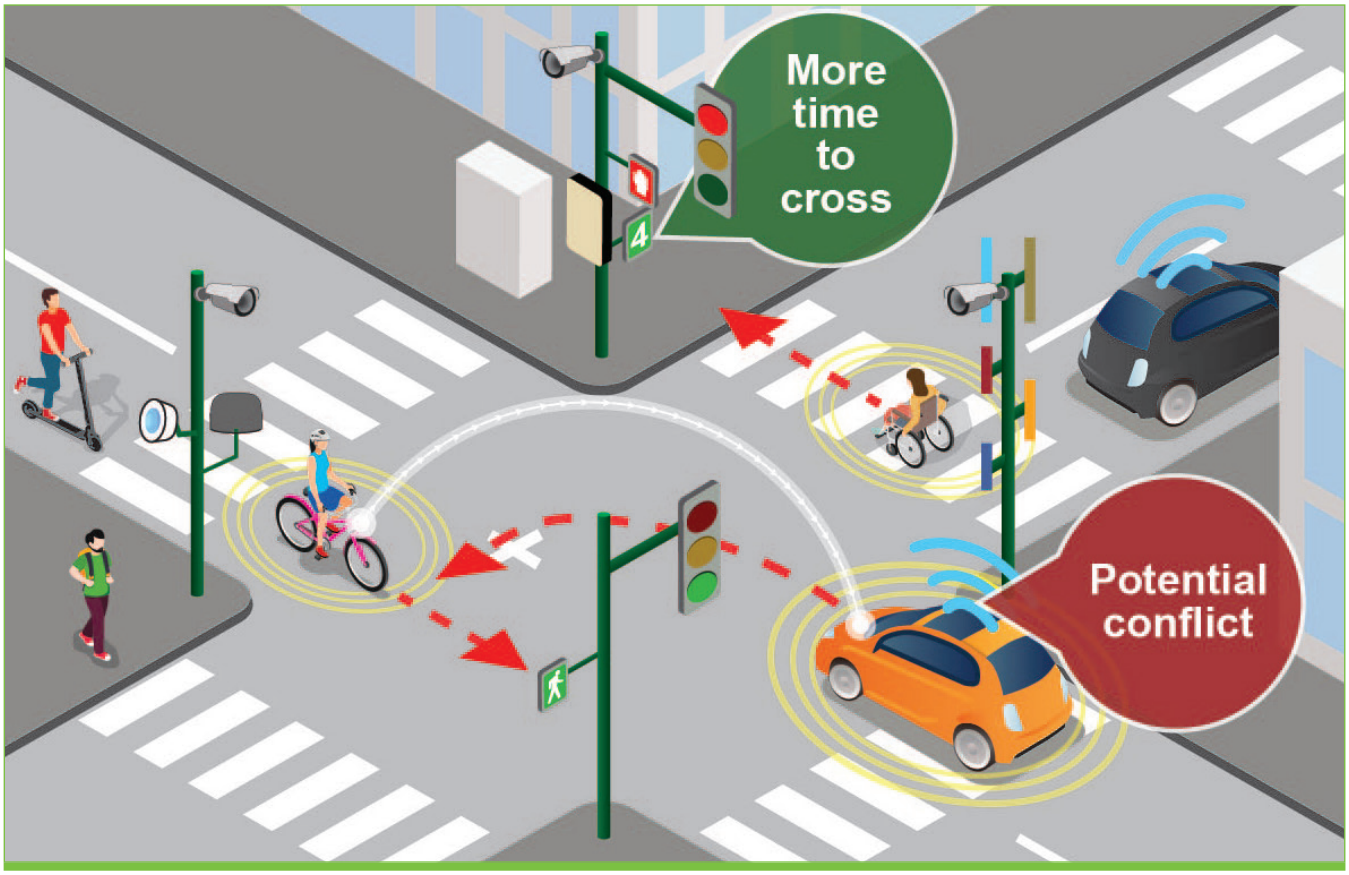
ADVANCED ARTIFICIAL INTELLIGENCE RESEARCH FOR EQUITABLE SAFETY OF VULNERABLE ROAD USERS

University of Tennessee at Chattanooga

This 2-yr project at the University of Tennessee at Chattanooga aims to develop a safe, AI-based, flexible, and equitable (SAIFE) system that can identify and track vulnerable road users (VRUs) and prevent potential vehicle−VRU collisions at intersections.[10] The SAIFE system project aims to detect, classify, and track VRUs at intersections while enhancing resiliency against sensor failure. This system will use various real-time sensors to create sensor fusion algorithms that can accurately classify VRUs. The SAIFE system will then perform AI-based multiple-object tracking and trajectory prediction, which will facilitate situational awareness, such as automated conflict and risk assessments.

Accepted for Publication and Presentation

1. Zhang, T., T. Bang, H. Abubakr, and M. Sartipi. 2024. “Vulnerable Road User Detection and Classification for Roadside LiDAR Units With Deep Embedding.” Accepted for presentation, Transportation Research Board Annual Meeting 2025.
2. Zhang, T. T. 2024. “Network Level Spatial Temporal Traffic Forecasting With Hierarchical Attention LSTM (HierAttnLSTM).” Accepted, *Digital Transportation and Safety*.
3. Zhang, T. T., Y. Ge, A. Chen, M. Sartipi, and P. J. Jin. 2024. “Hash-Based Gaussian Mixture Model for Roadside LiDAR Smart Infrastructure Applications.” *IEEE Transactions on Intelligent Transportation Systems* 25, no. 10: 12968–12979. https://ieeexplore.ieee.org/document/10624598, last accessed October 24, 2024.



Simulated example of SAIFE system in use.[10]

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.[11] 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 Presentation

1. Dash, A., G. Wang, and T. Han. 2024. "Attentive Partial Convolution for RGBD Image Inpainting." In *WWW '24: Companion Proceedings of the ACM Web Conference 2024*. New York, NY: Association for Computing Machinery. 1410–1417.

2. Yao, W., W. Du, J. Gu, J. Ye, F. P. Deek, and G. Wang. 2024. "Establishing a Baseline for Evaluating Blockchain-Based Self-Sovereign Identity Systems: A Systematic Approach to Assess Capability, Compatibility, and Interoperability." Presented at *BIOTC 2024*. Fukuoka, Japan.

3. Yao, W., N. Gorlewski, F. P. Deek, and G. Wang. 2024. "Considerations for Decision Makers and Developers Toward the Adoption of Decentralized Key Management Systems Technology in Emerging Applications." *Computer* 57, no. 7: 27–38.

4. Ye, J., M. Du, and G. Wang. 2024. "DataFrame QA: A Universal LLM Framework on DataFrame Question Answering Without Data Exposure." *arXiv*. https://arxiv.org/abs/2401.15463, last accessed October 18, 2024.

WASTE PLASTICS IN ASPHALT BINDERS

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

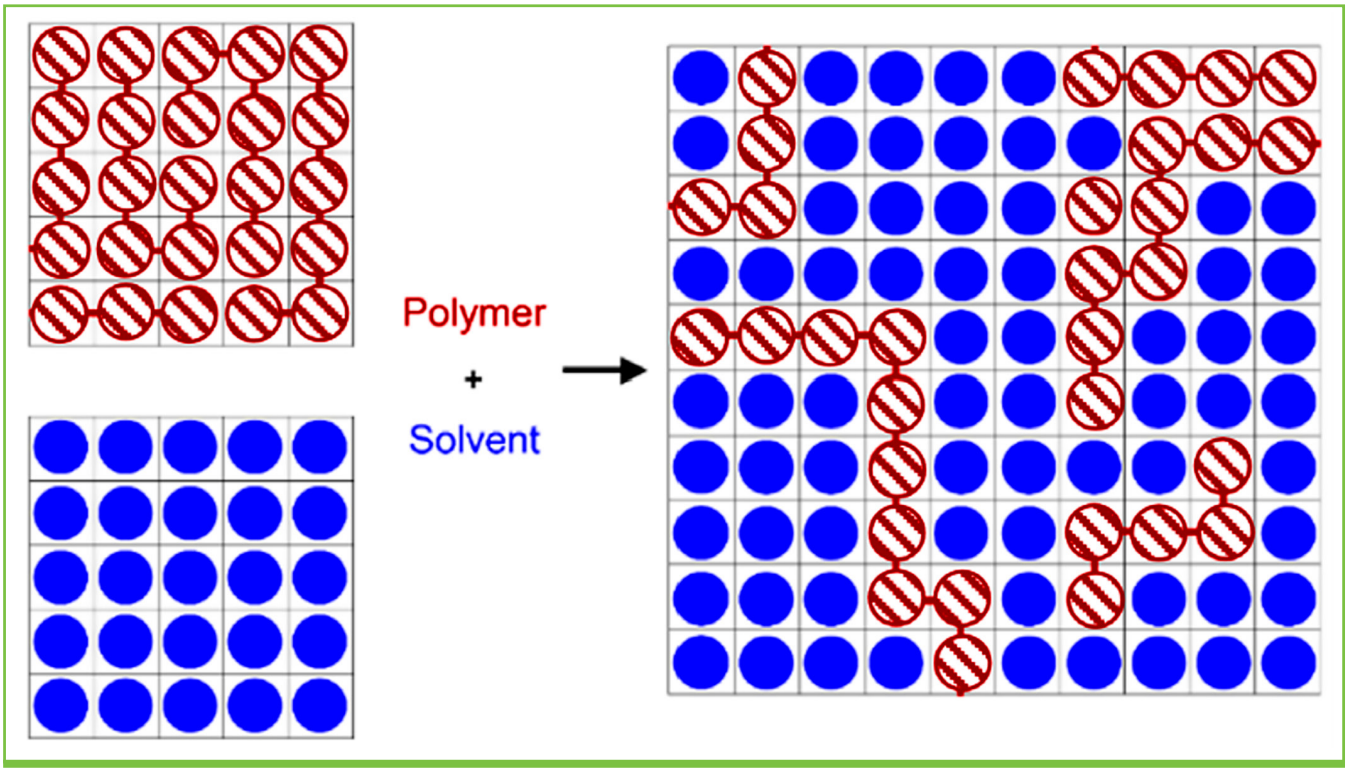
Louisiana Tech University

Waste plastic, though largely considered an environmental concern, has the potential to be a valuable resource.[12] 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. 2024. "Investigation of Polymer-Asphalt Compatibility Using Molecular Dynamics Simulation." *The Journal of Physical Chemistry B* 128, no. 19: 4821–4829. https://pubs.acs.org/doi/10.1021/acs.jpcb.4c00672, last accessed October 11, 2024.

2. Elnaml, I., J. Liu, L. N. Mohammad, N. M. Wasiuddin, S. Cooper, III, and S. Cooper, Jr. 2023. "Developing Sustainable Asphalt Mixtures Using High-Density Polyethylene Plastic Waste Material." *Sustainability* 15, no. 13: 1–15. https://doi.org/10.3390/su15139897, last accessed October 11, 2024.



The model used to calculate the compatibility of different polymers and asphalt (the "solvent" in the figure).[12]

INTERAGENCY RESEARCH

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

MAKING MICROMOBILITY SMARTER AND SAFER

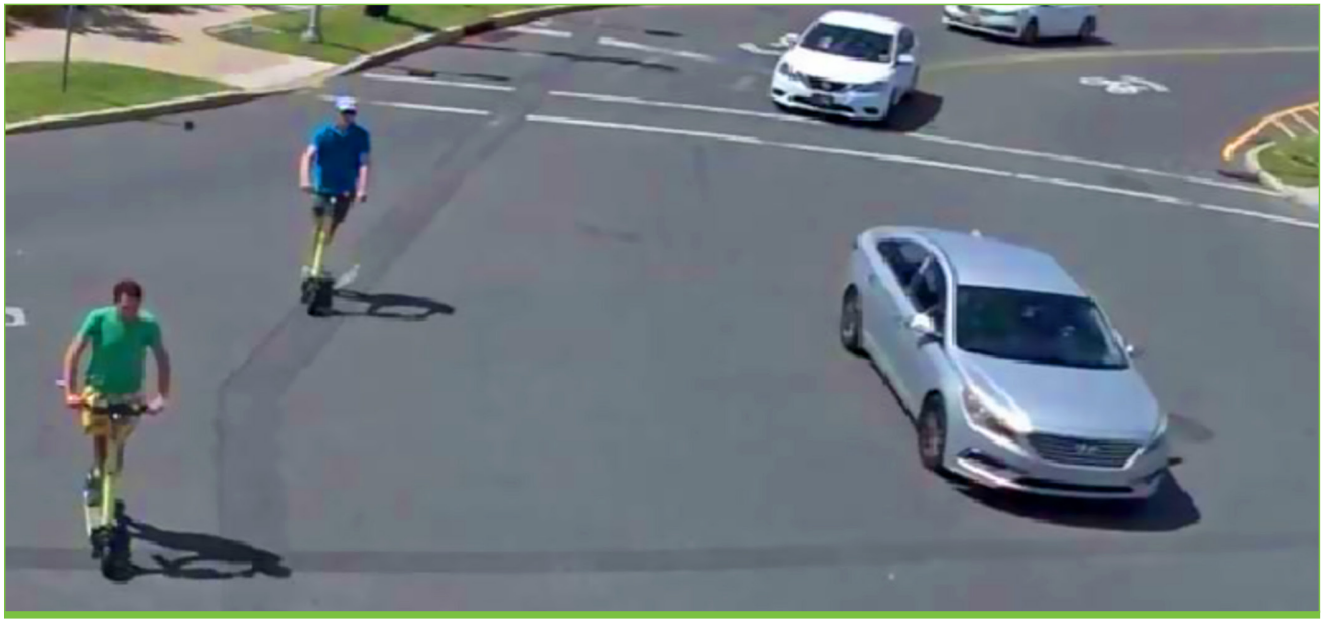
Rutgers University

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 has been staggering over the past decade.[13] From 2010 to 2019, shared micromobility vehicle ridership ballooned from 321,000 trips annually in 2010 to 136 million annually in 2019.[14] In 2020, travelers in the United States took an estimated 67.9 million trips on shared micromobility vehicles.[15] 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. Wang, G., Z. Qin, S. Wang, H. Sun, Z. Dong, and D. Zhang. 2024. “Towards Accessible Shared Autonomous Electric Mobility With Dynamic Deadlines.” *IEEE Transactions on Mobile Computing* 23, no. 1: 925–940. https://ieeexplore.ieee.org/document/9914659, last accessed October 21, 2024.

2. Yang, G., Y. Zhang, J. Hang, X. Feng, Z. Xie, D. Zhang, and Y. Yang. 2023. “CARPG: Cross-City Knowledge Transfer for Traffic Accident Prediction Via Attentive Region-Level Parameter Generation.” In *Proceedings of the 32nd ACM International Conference on Information and Knowledge Management*. New York: NY: Association for Computing Machinery. 2939–2948. https://dl.acm.org/doi/abs/10.1145/3583780.3614802, last accessed October 21, 2024.



E-scooters being used alongside car traffic.[13]

HYBRID TWINS FOR URBAN TRANSPORTATION: FROM INTERSECTIONS TO CITYWIDE MANAGEMENT

Columbia University

Traffic management in metropolitan areas poses distinct challenges.[16] 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)

Accepted for Publication and Presentation

1. Fu, Y. J., M. Turkcan, V. Anantha, Z. Kostic, G, Zussman, and X. Di. 2024. "Digital Twin for Pedestrian Safety Warning at a Single Urban Traffic Intersection." In *IEEE Intelligent Vehicles Symposium (IV)*. Piscataway, NJ: IEEE.

2. Turkcan, M., S. Narasimhan, C. Zang, G. Je, B. Yu, M. Ghasemi, J. Ghaderi, G. Zussman, and Z. Kostic. 2024. "Constellation Dataset: Benchmarking High-Altitude Object Detection for an Urban Intersection." *arXiv*. https://arxiv.org/html/2404.16944v1, last accessed October 21, 2024.

3. Zang, C., M. Turkcan, G. Zussman, J. Ghaderi, and Z. Kostic. 2024. *Data-Driven Traffic Simulation for an Intersection in a Metropolis*. New York, NY: Columbia University. https://openreview.net/pdf/074c84de74414095546417336eabb8c267f97f68.pdf, last accessed October 21, 2024.

The researchers are using cameras to capture traffic data.[16]

REFERENCES

1. FHWA. 2020. *Utilizing Mobile Ad Hoc Networks to Enhance Road Safety*. Publication No. FHWA-HRT-20-046. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-20-046.pdf, last accessed October 21, 2024.

2. FHWA. 2024. *Digital Twin-Enabled Extended Active Safety Analysis for Mixed Traffic*. Publication No. FHWA-HRT-24-054. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-054.pdf, last accessed October 2, 2024.

3. 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.

4. 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.

5. FHWA. 2020. *Researching Novel Approaches for Aging Resistant Binder Technologies*. Publication No. FHWA-HRT-20-051. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/ear/20051/20051.pdf, last accessed October 3, 2024.

6. FHWA. 2023. *Cooperative Perception and Control for Traffic System Operations*. Publication No. FHWA-HRT-23-105. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-105.pdf, last accessed October 3, 2024.

7. FHWA. 2024. *Predictive Real-Time Traffic Management in Large-Scale Networks Using Model-Based Artificial Intelligence*. Publication No. FHWA-HRT-23-107. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-23-107.pdf, last accessed October 21, 2024.

8. 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.

9. 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.

10. FHWA. 2024. *Using Artificial Intelligence To Improve Safety for Vulnerable Road Users*. Publication No. FHWA-HRT-24-080. Washington, DC: Federal Highway Administration. https://highways.dot.gov/sites/fhwa.dot.gov/files/FHWA-HRT-24-080.pdf, last accessed October 2, 2024.

11. 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.

12. 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.

13. 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.

14. 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.

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

16. 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 solving problems. The program bridges basic research (e.g., academic work funded by National Science Foundation grants) and applied research (e.g., studies funded by State departments of transportation). In addition to sponsoring EAR Program projects that advance the development of highway infrastructure and operations, the EAR Program is committed to promoting cross-fertilization with other technical fields, furthering promising lines of research, and deepening vital research capacity.

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: Updated for 2024* (Washington, DC: 2024) https://doi.org/10.21949/1521535

FHWA-HRT-25-018
HRT-10/12-24(30)E